IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

Studying the Universe Underground

Hitoshi Murayama (IPMU Tokyo & Berkeley)

Physics Colloquium, BNL, Oct 16, 2008

BERKELEY CENTER FOR THEORETICAL PHYSICS

BERKELEY LAB

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

- New intl research institute in Japan
    - astrophysics
    - particle theory
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INSTITUTE FO
MATHEMATIC

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For the agency/public:

- What is the Universe made of?
- How did it start?
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translation for you:

- nature of dark matter

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- string theory, unification, proton decay
- origin of baryon asymmetry

IPMU initiatives in experiments

- Vagins: let SuperK detect neutrinos from long past supernovae
- Kozlov: use KamLAND to see if $\nu=\bar{\nu}$?
- Suzuki/Nakahata/Martens: XMASS to detect dark matter
- Aihara/Takada/Yoshida/Spergel/Turner: leadership in designing new camera HSC at Subaru and data analysis to study dark energy
- Also new photodetector developments (e.g. HPD)

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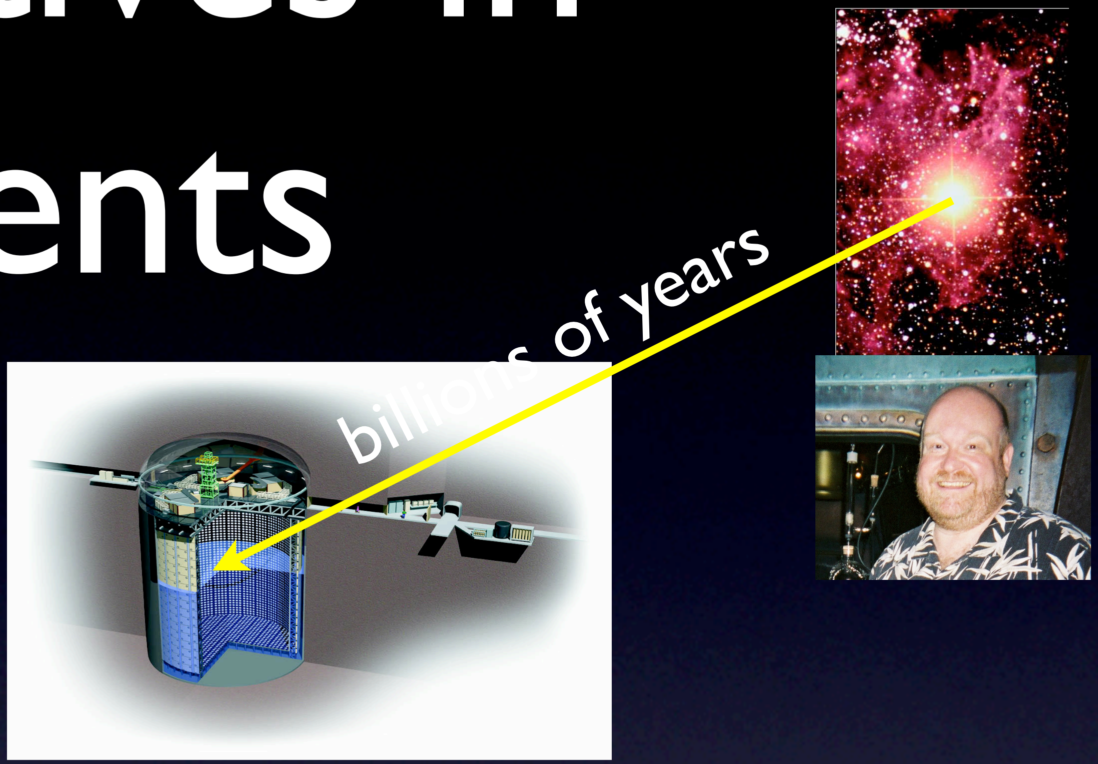

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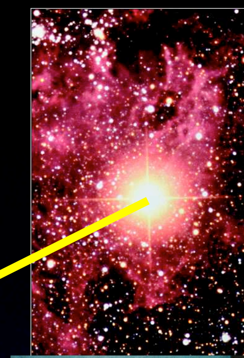

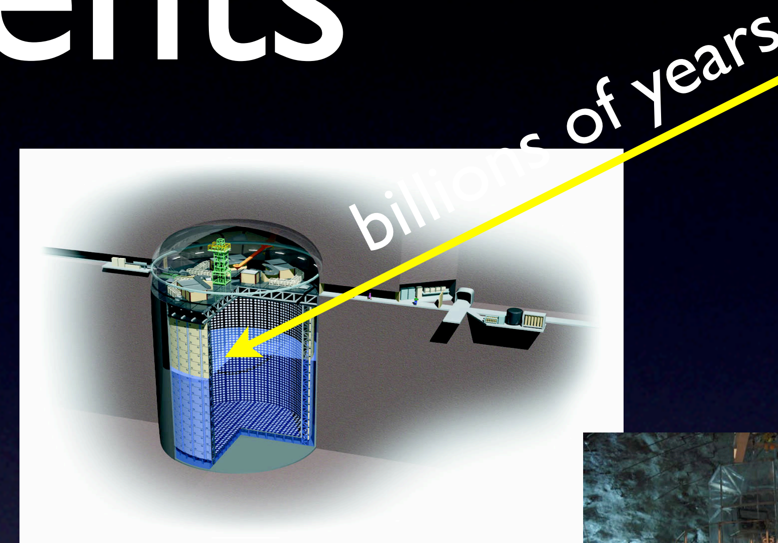

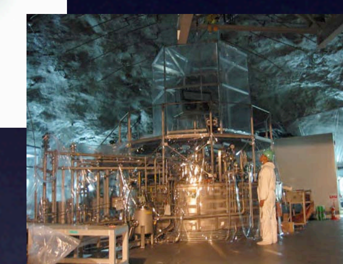

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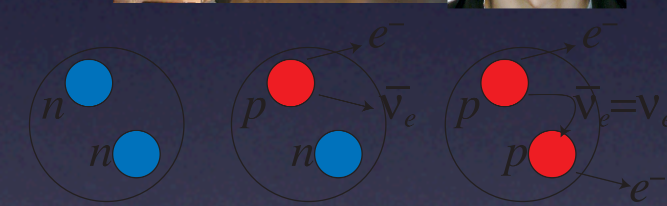

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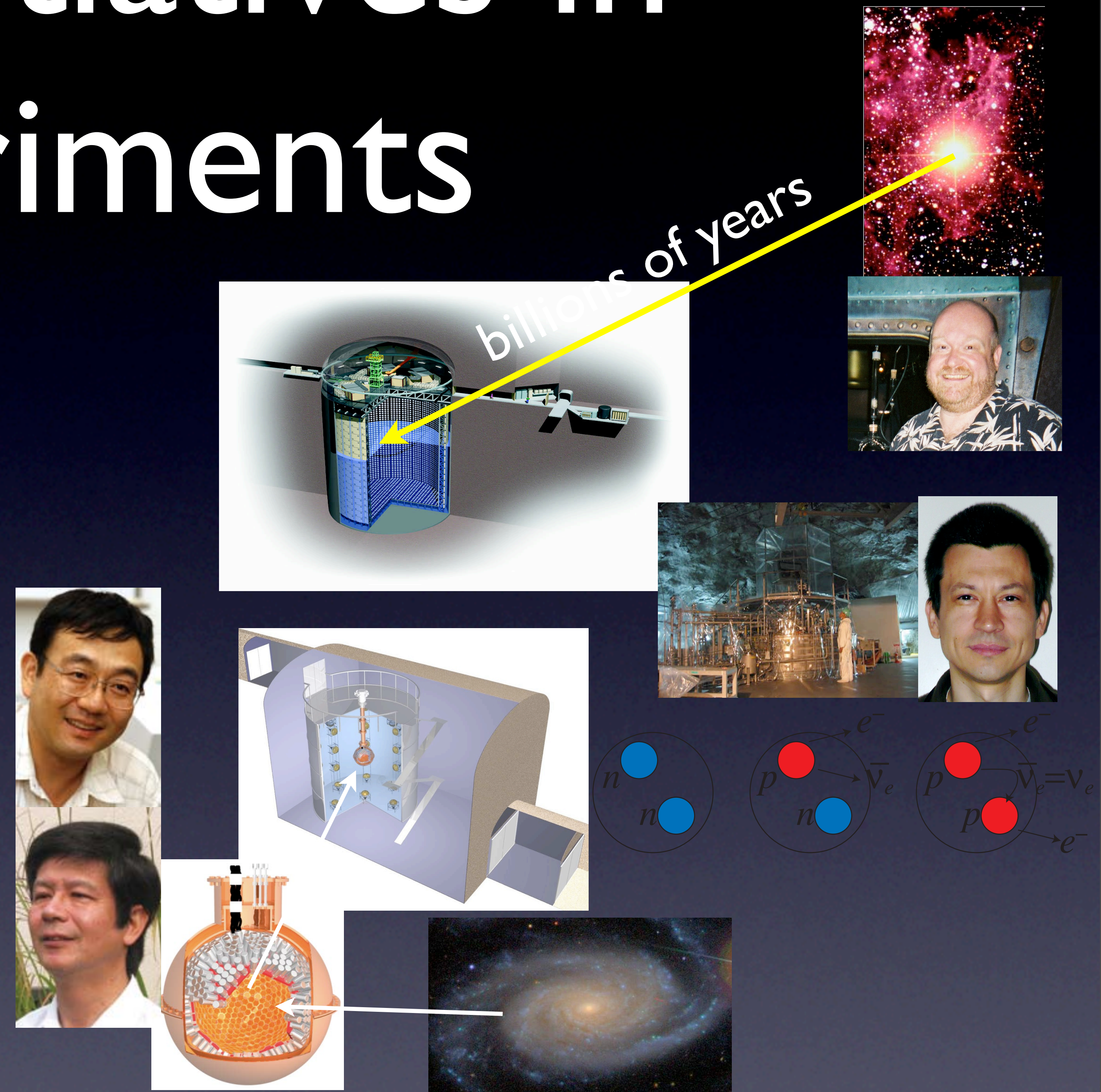

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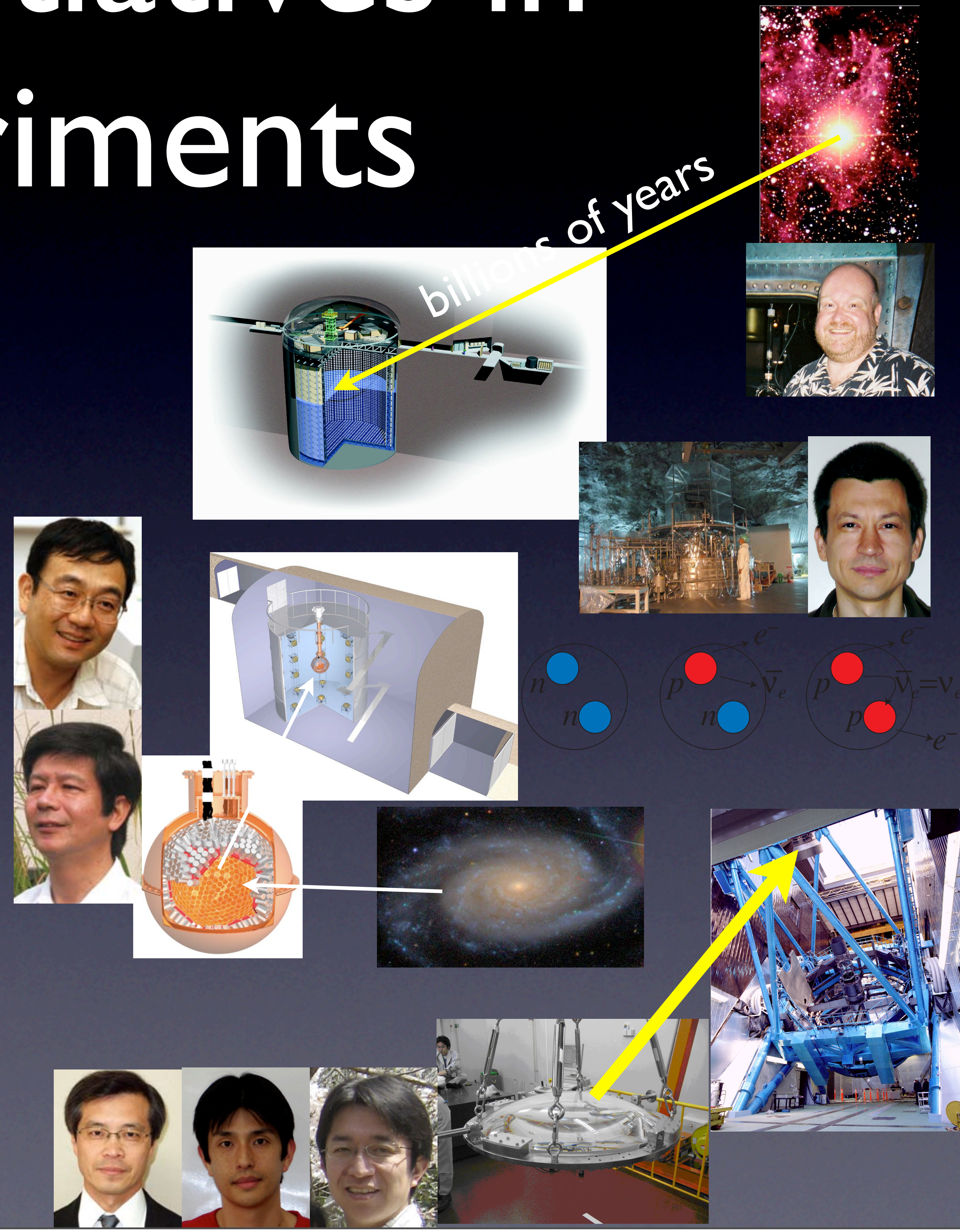


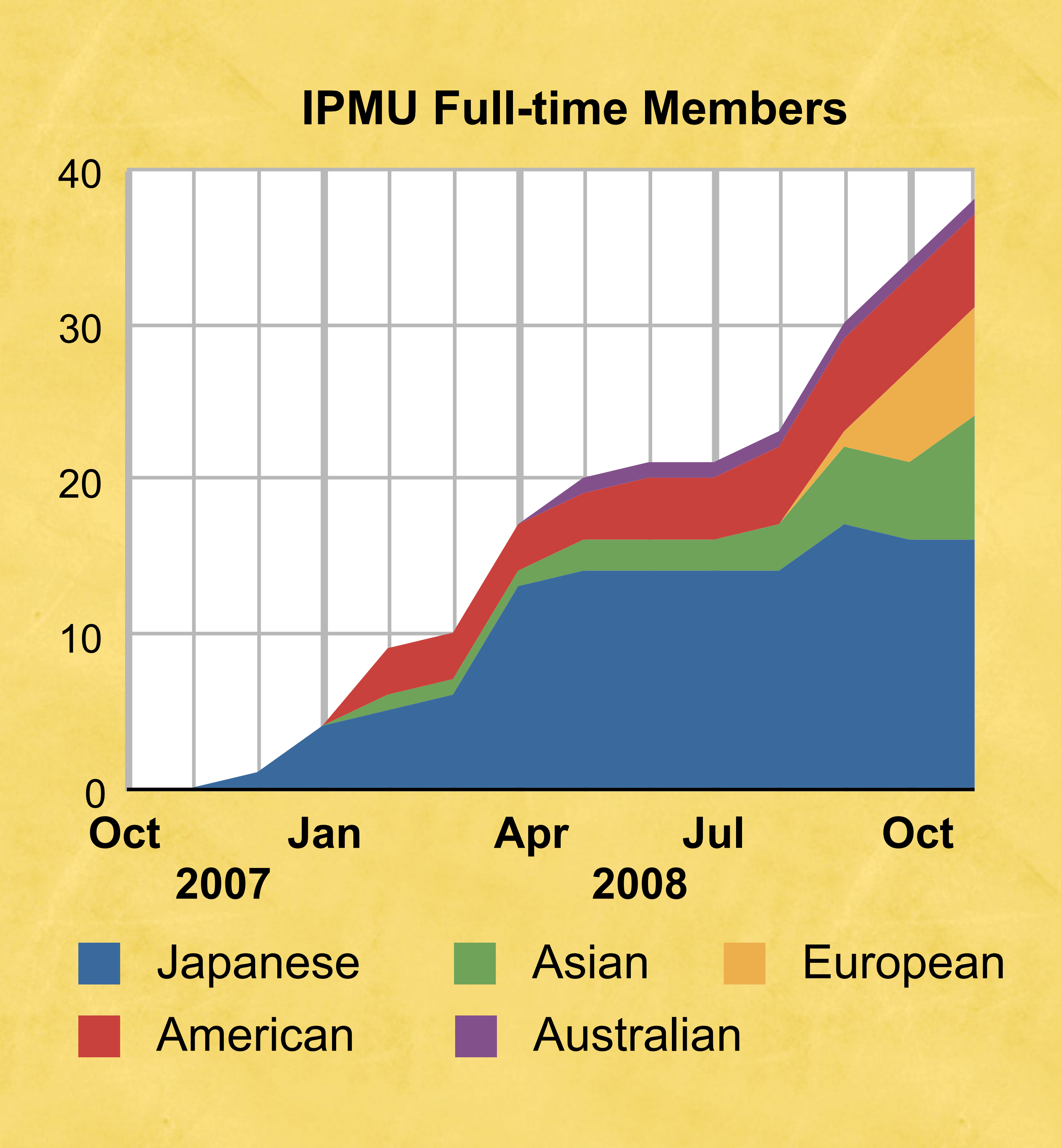
Winter 2009 occupancy

~5900m^2

emphasis on large interaction area

"like a European town square" ~400 m^2

On Site Scientists



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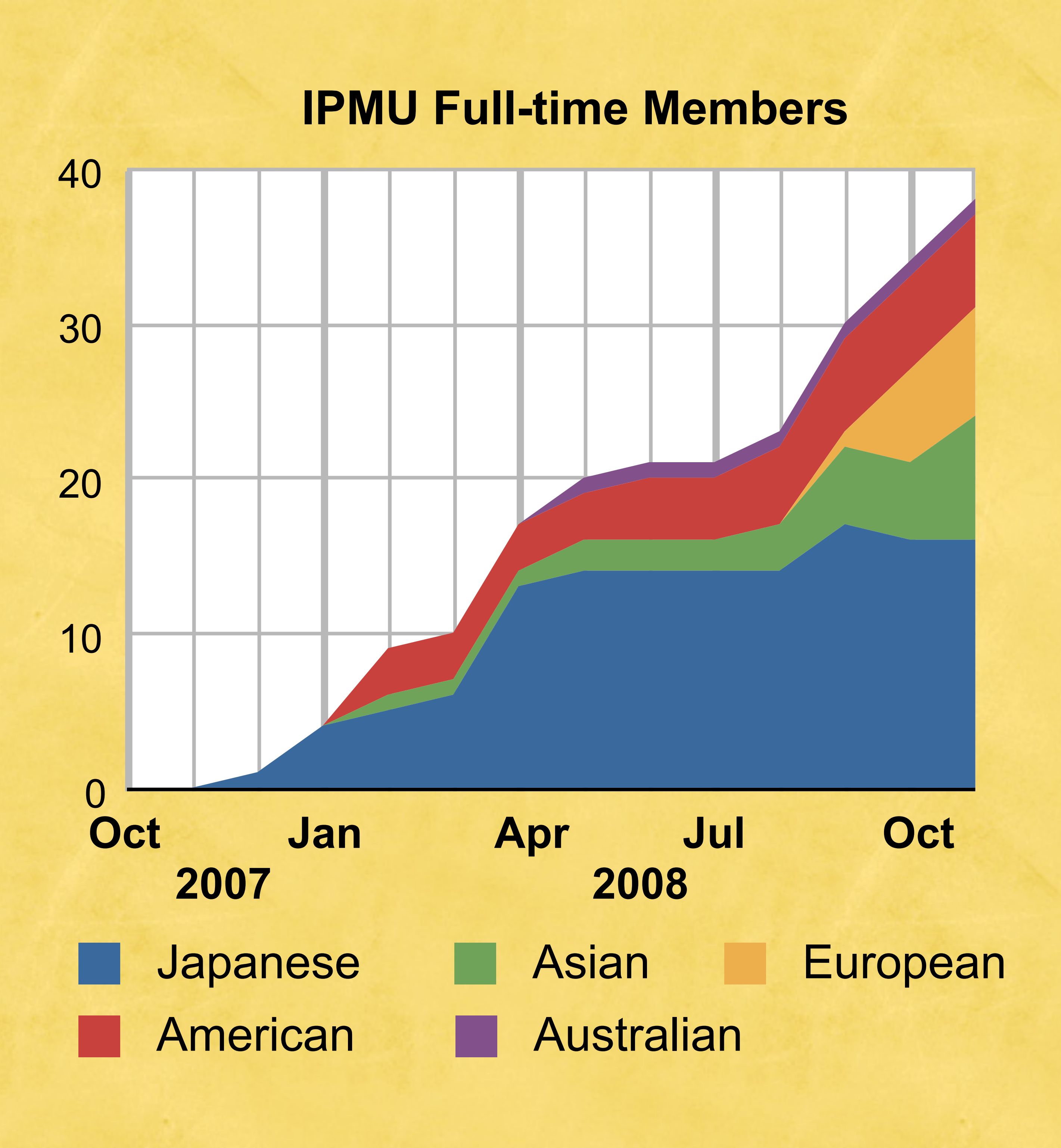
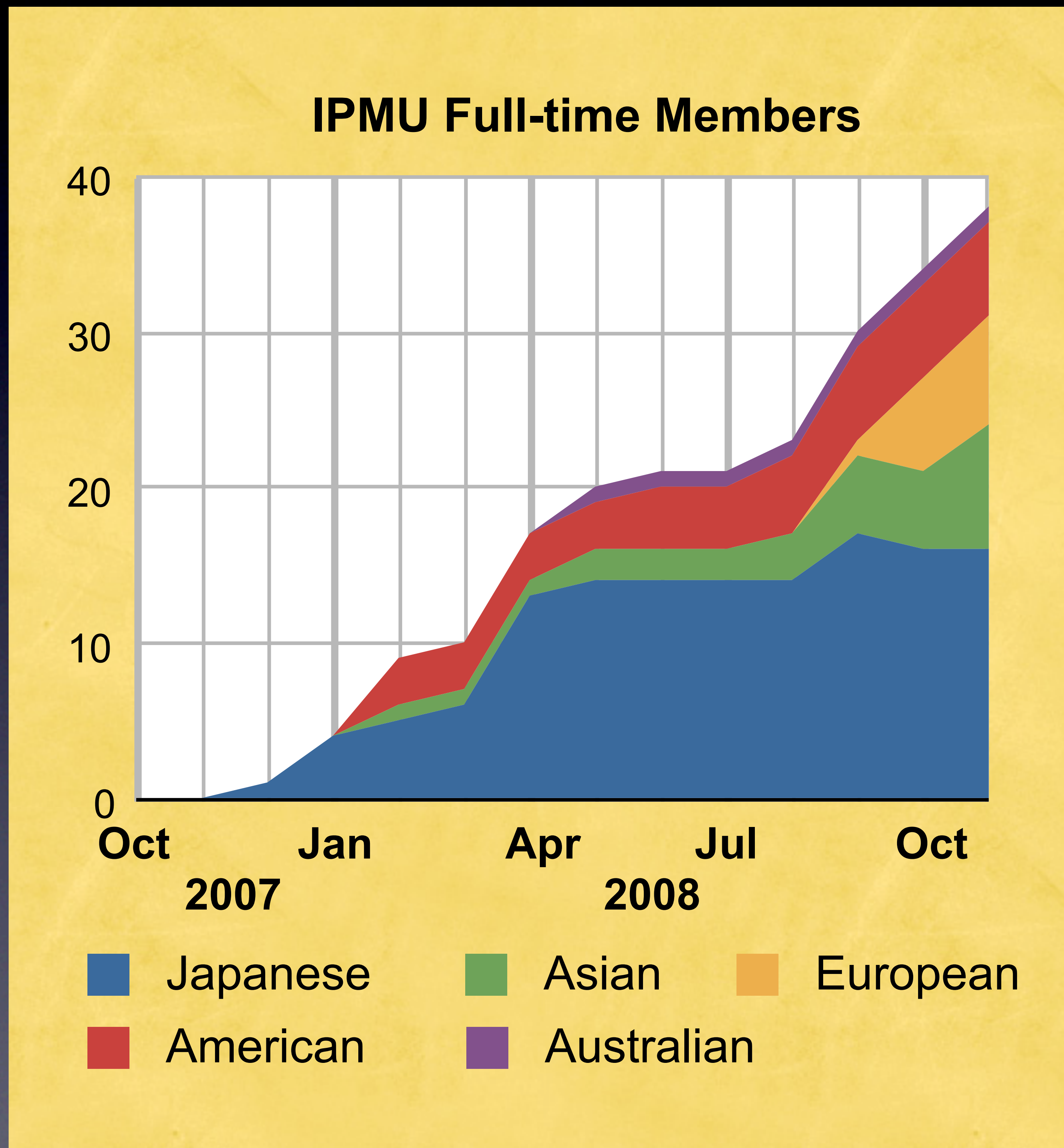


non-Japanese 50%

On Site Scientists



Expect ~15 positions this year

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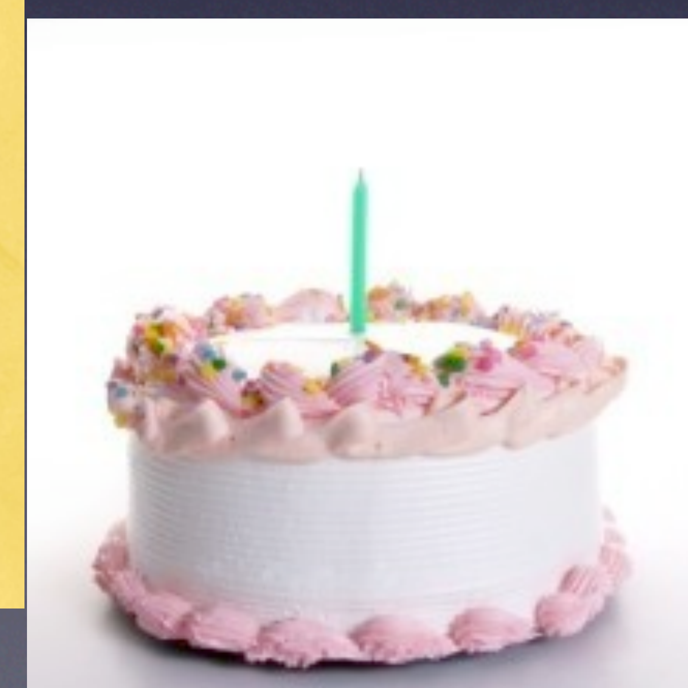

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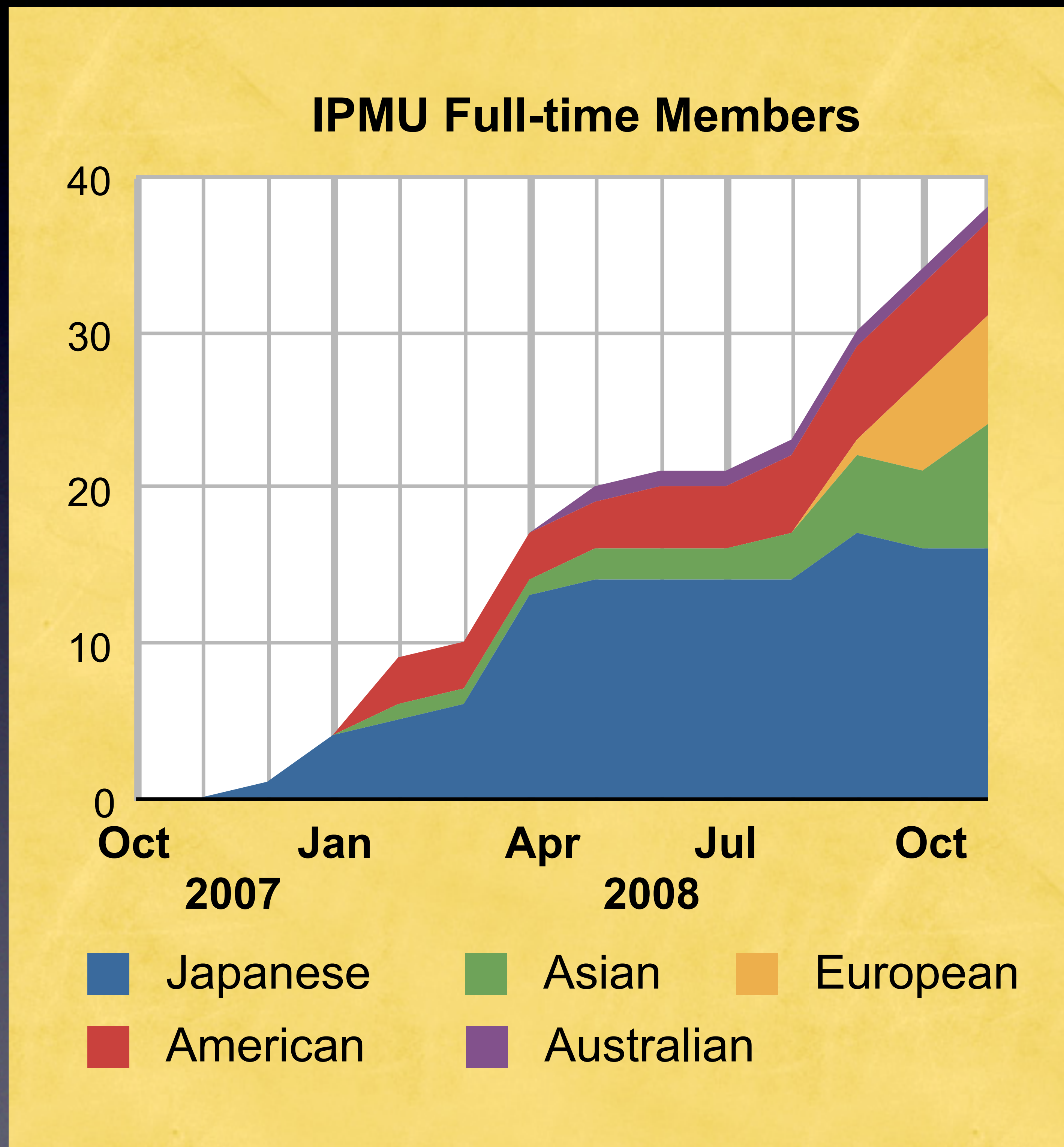
Check out www.ipmu.jp



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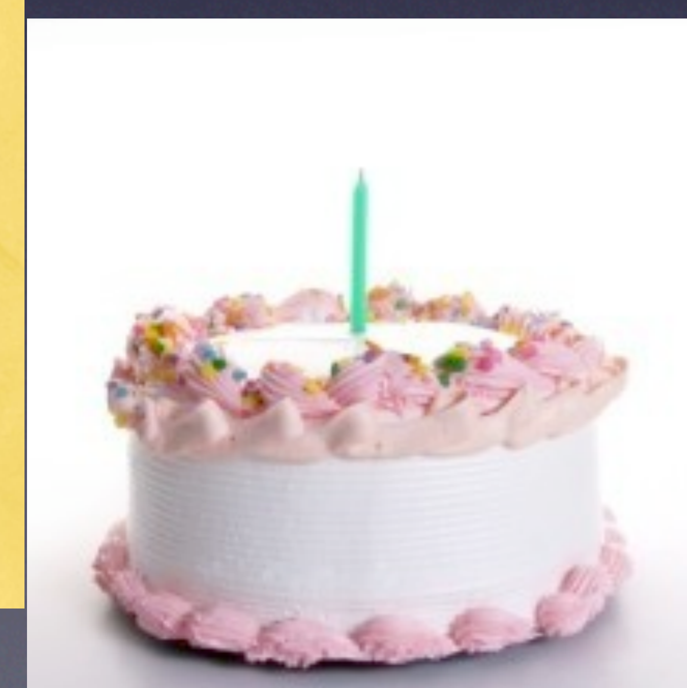

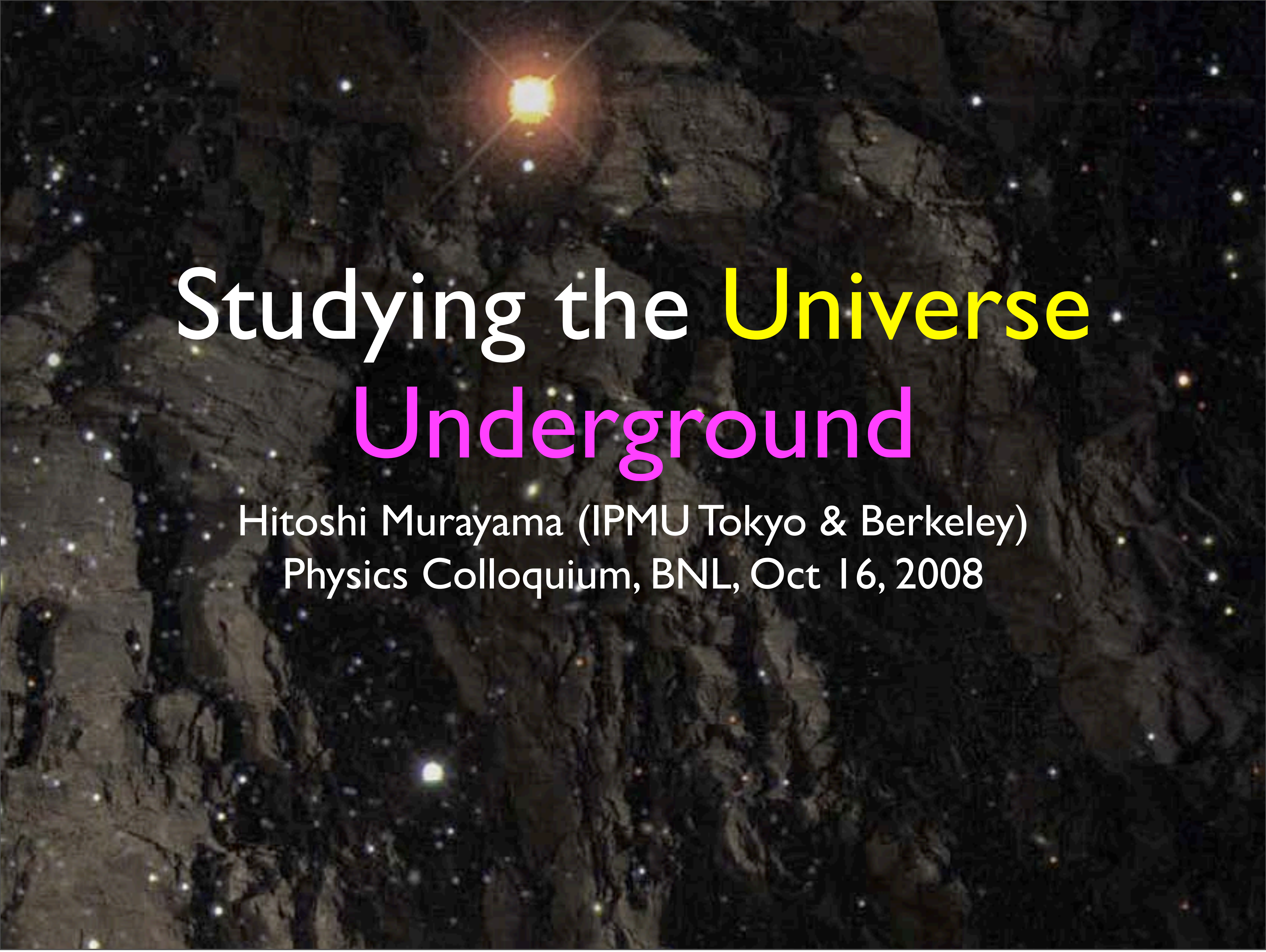

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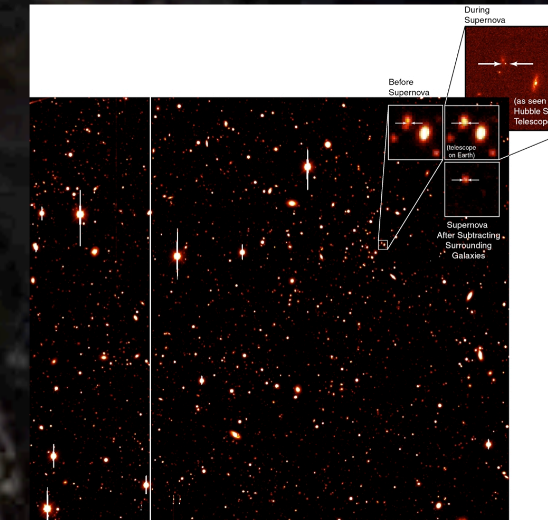
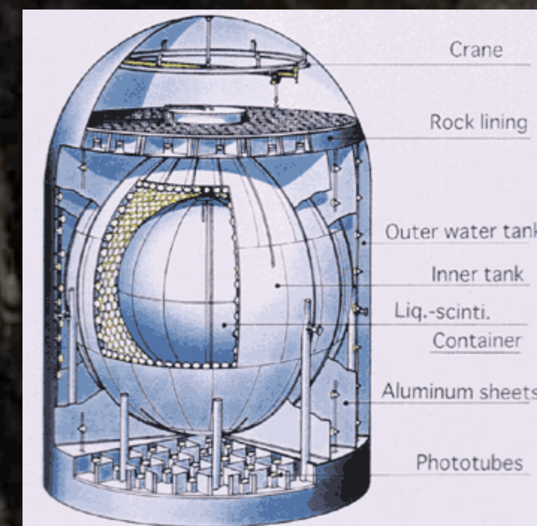
MIT
FLAVOR PHYSICS

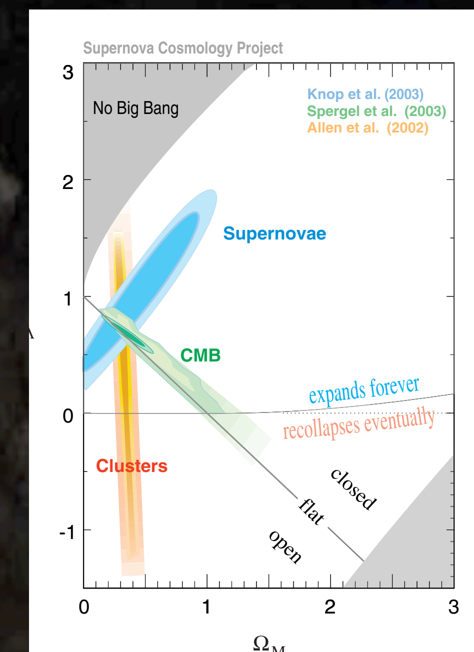

There are many things we don't see



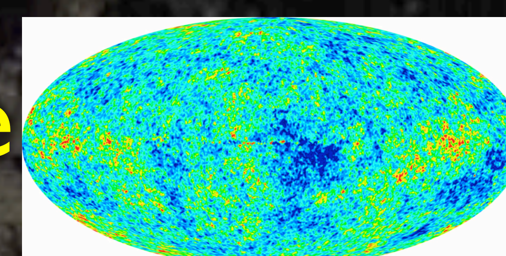
Exciting time

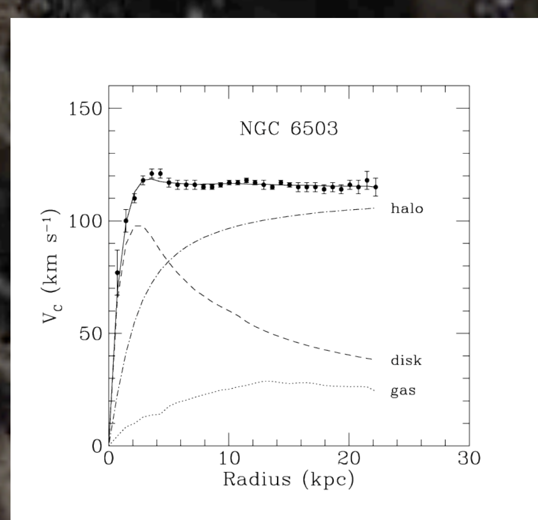
- Dark Matter
- Dark Energy
- Neutrino mass
- cosmic ripples

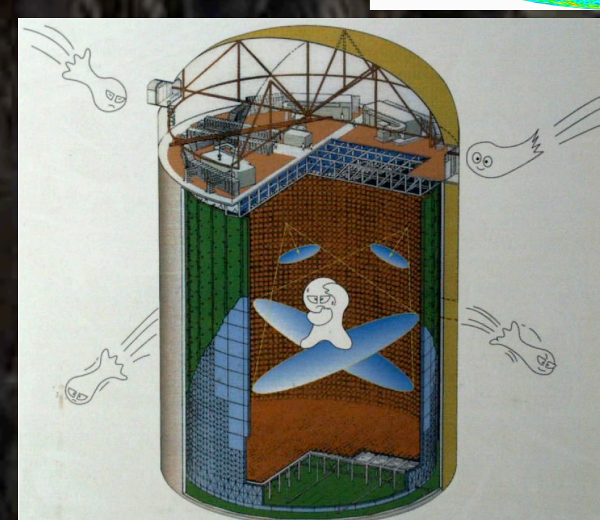


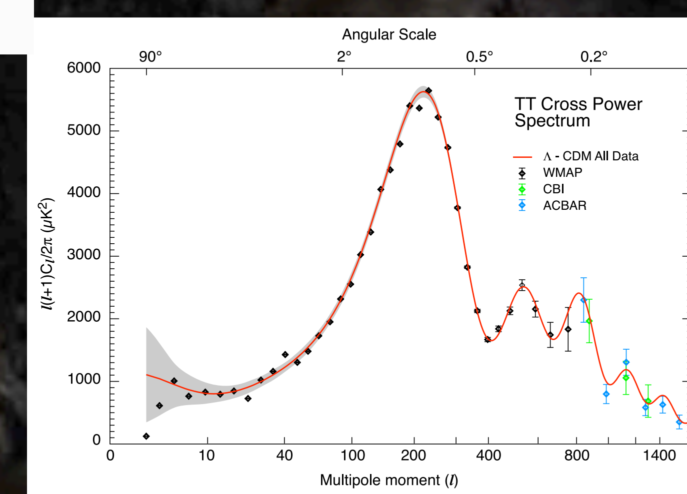


Data-driven science



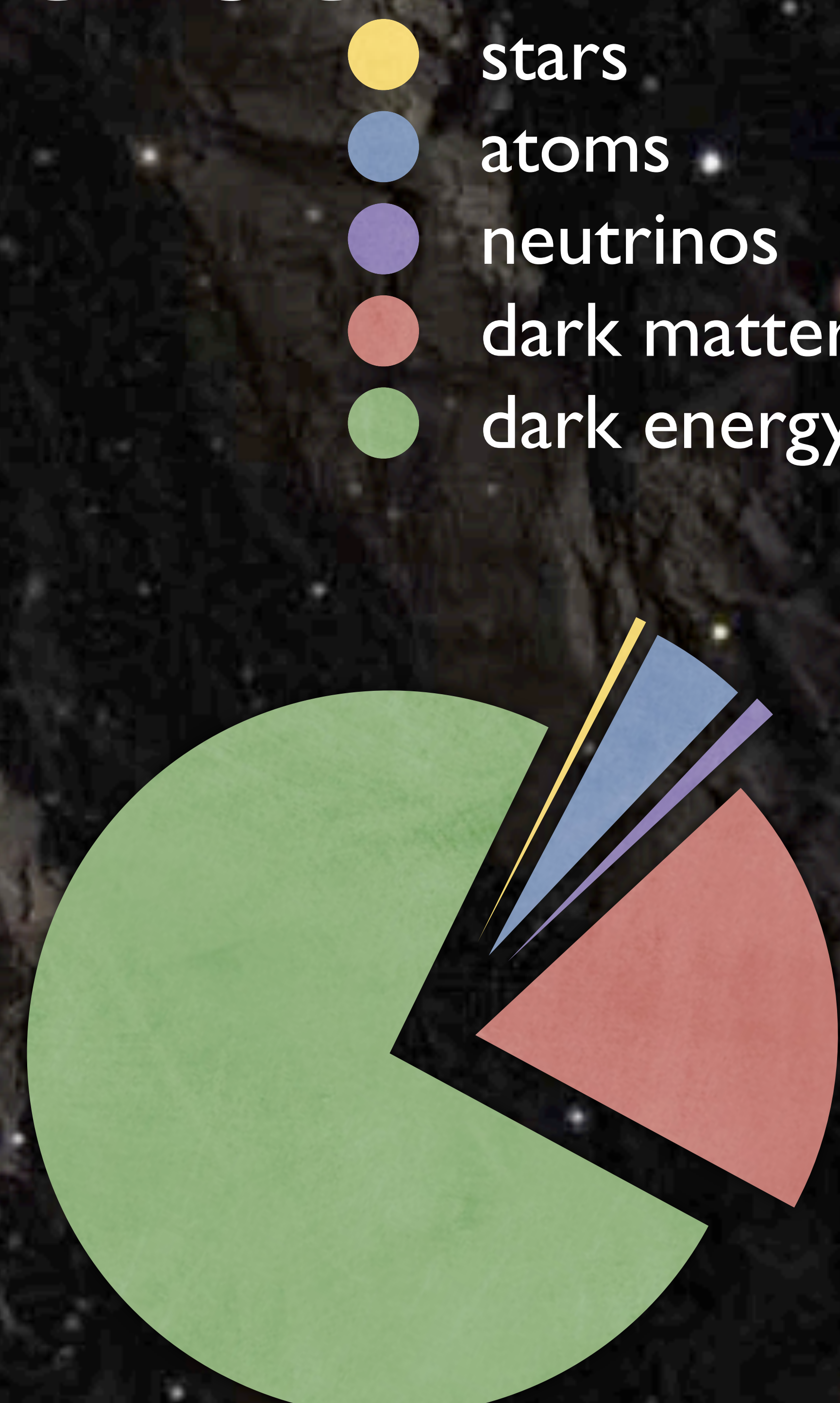






Energy Budget of the Universe

- Stars are only ~0.5%



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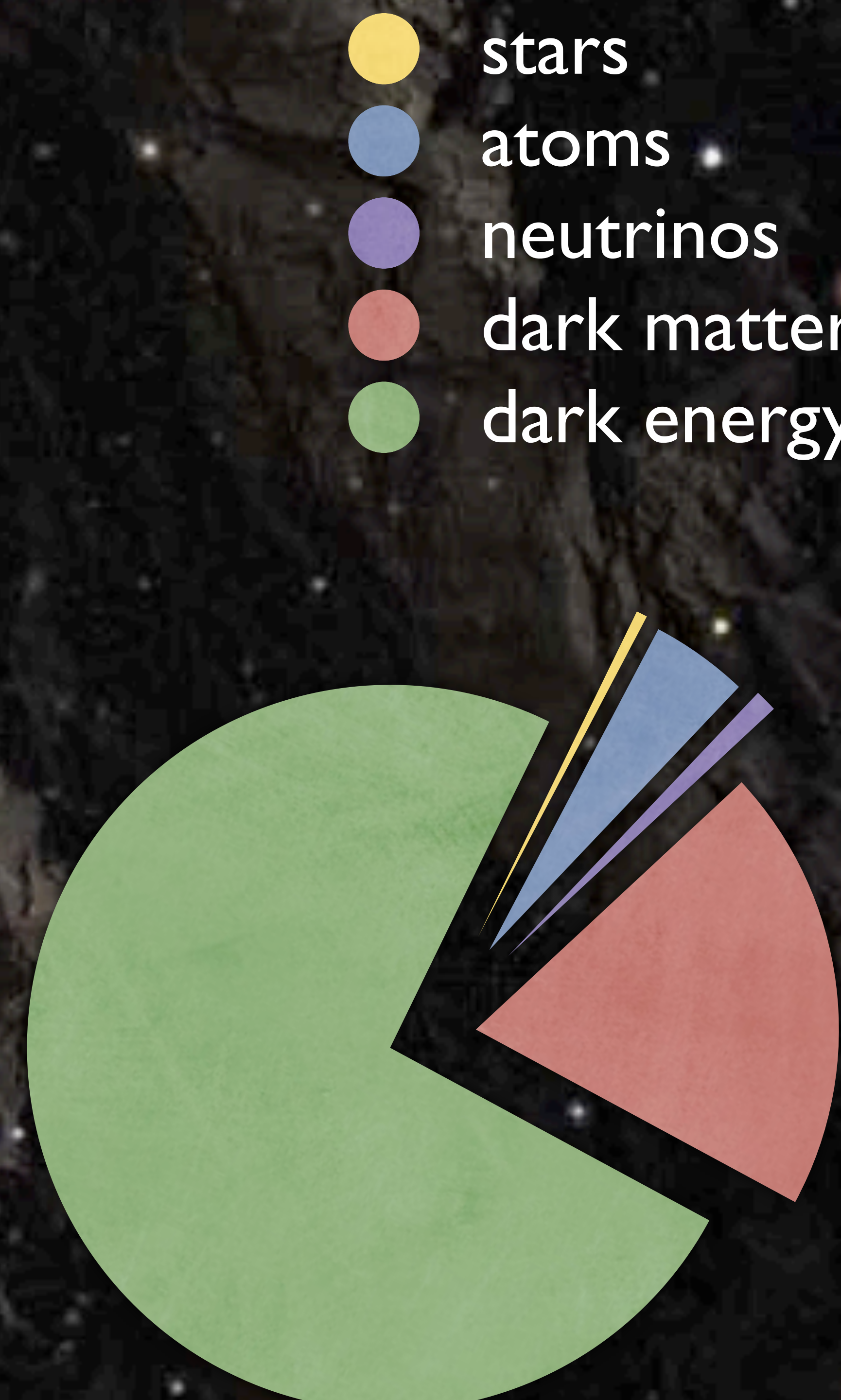
- Stars are only ~0.5%
- Neutrinos are ~0.1–1.5%



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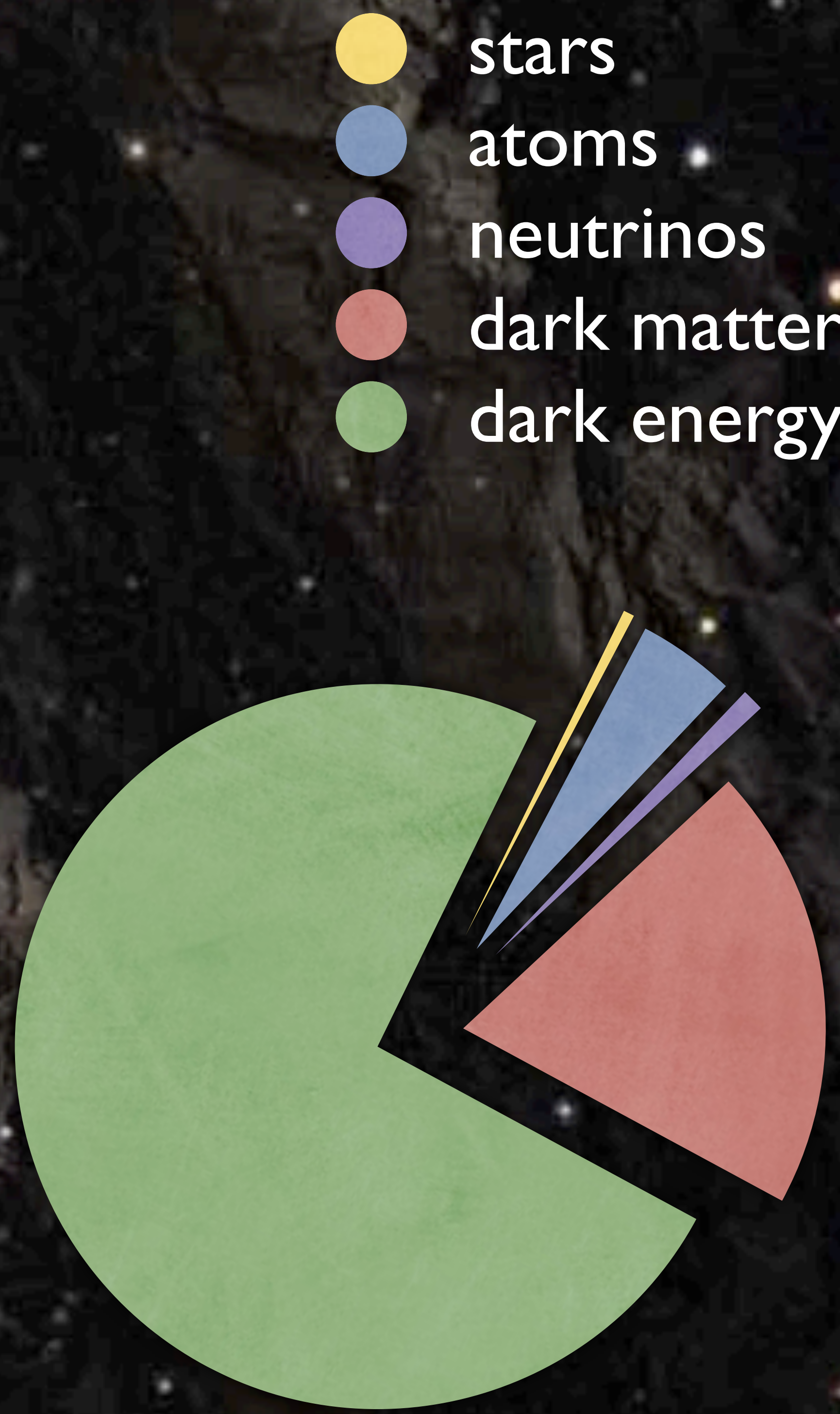
- Rest of ordinary matter (atoms) 4.4%



Energy Budget of the Universe

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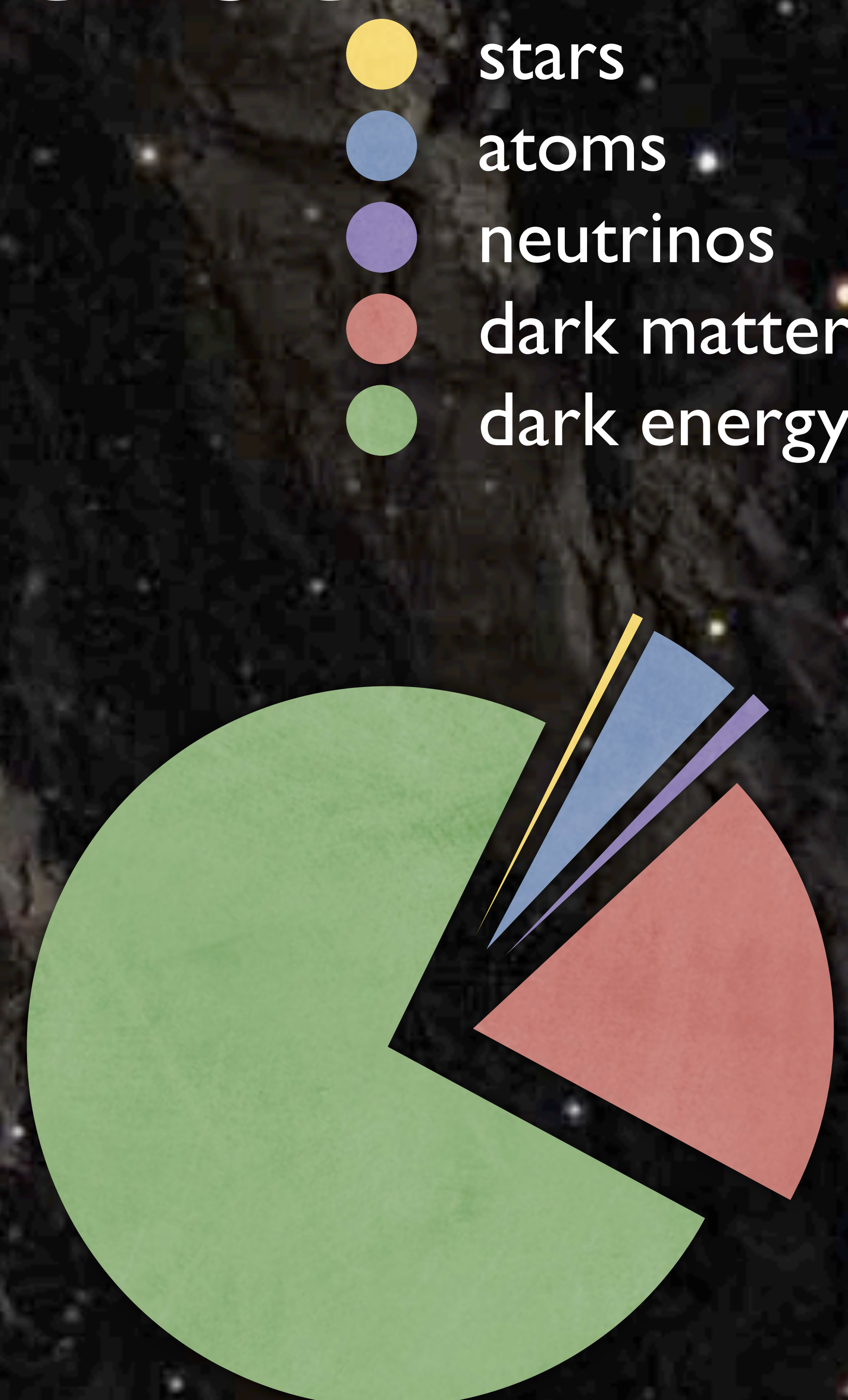
- Rest of ordinary matter (atoms) 4.4%
- Dark Matter 20%



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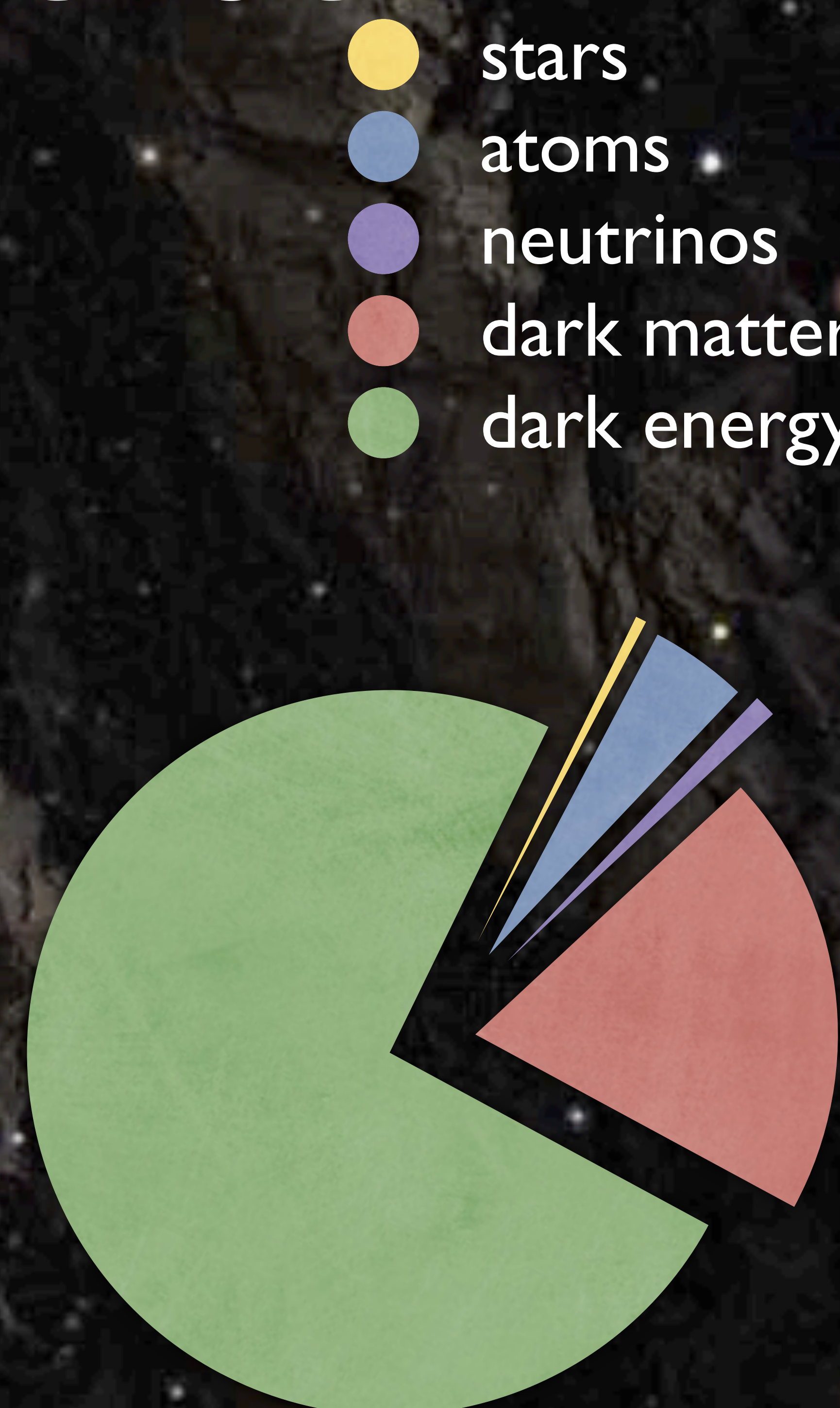
- Dark Energy 75%



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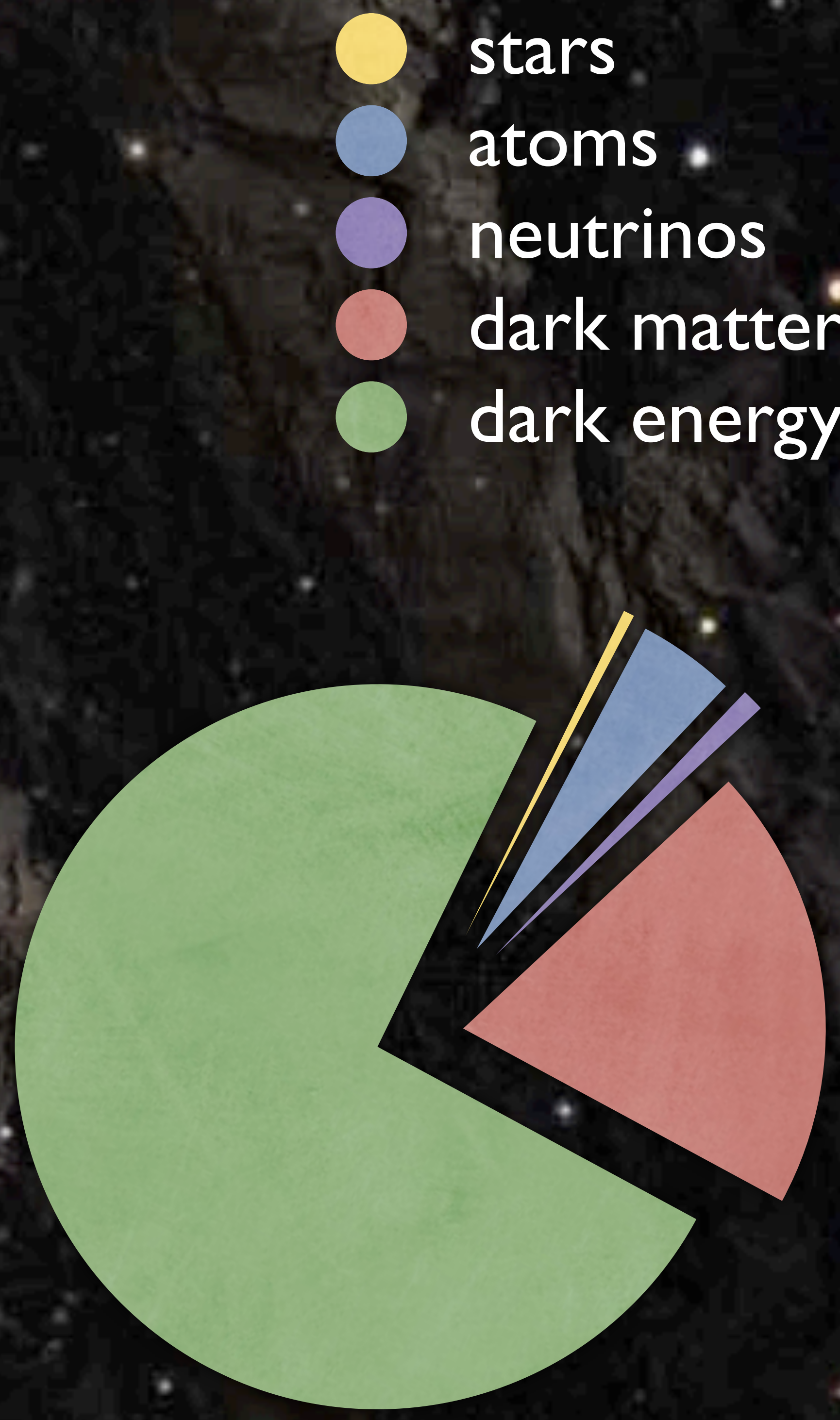

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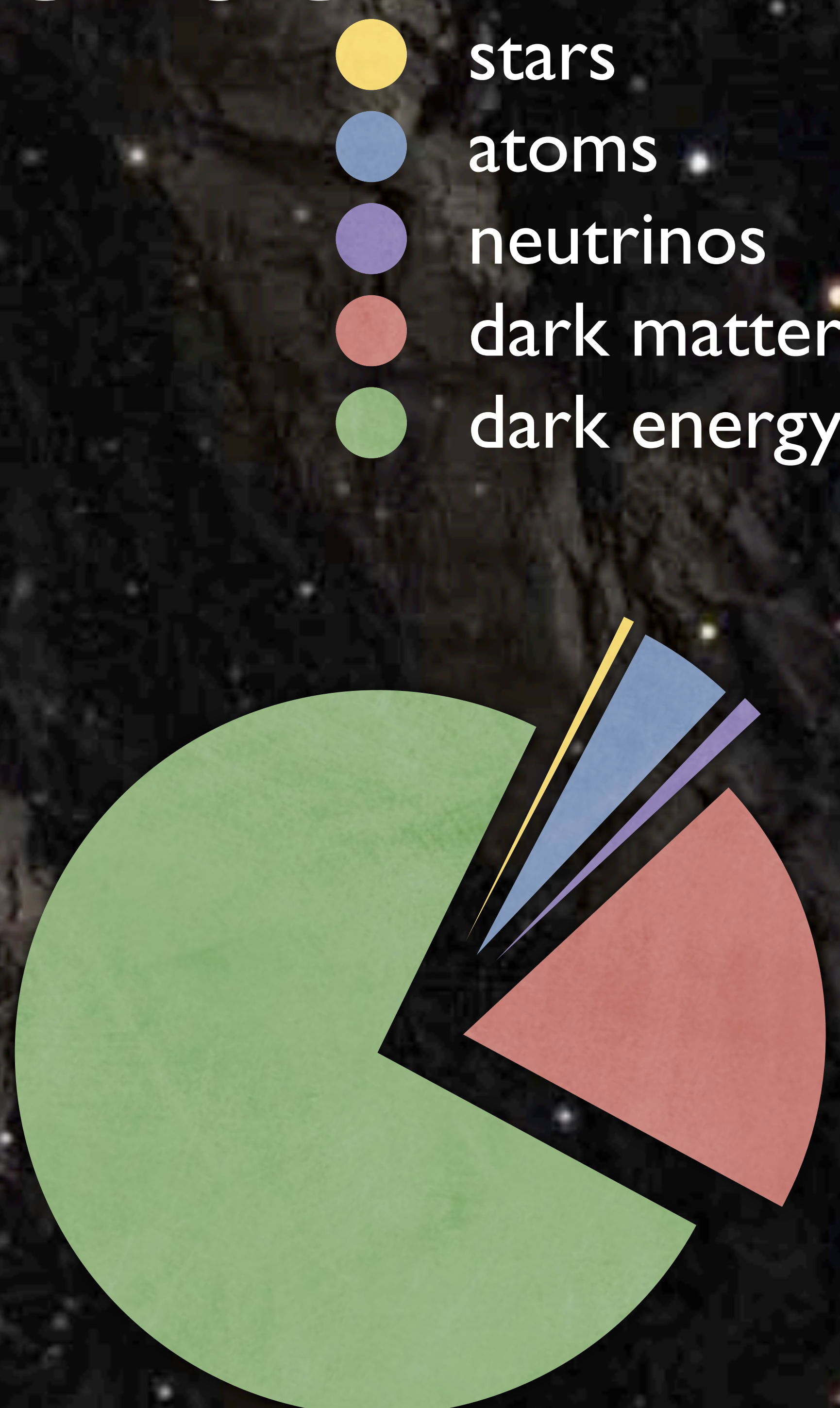

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stars
atoms
neutrinos
dark matter

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"The deficit poses a significant obstacle to long-term stability"

Energy Bu
of the Un


"All the News That's Fit to Print"

The New York Times

NEW YORK, TUESDAY, SEPTEMBER 16, 2008

GEORGIA OFFERS FRESH EVIDENCE ON WAR'S START

RECORDED PHONE CALLS

Tracing Troop Moves — Russia Rejects Claim It Was Aggressor

On Peninsula In the Storm: No Way Out

After 4 Days, 'Miracle' for a Texas Couple

WALL ST. IN WORST LOSS SINCE '01 DESPITE REASSURANCES BY BUSH

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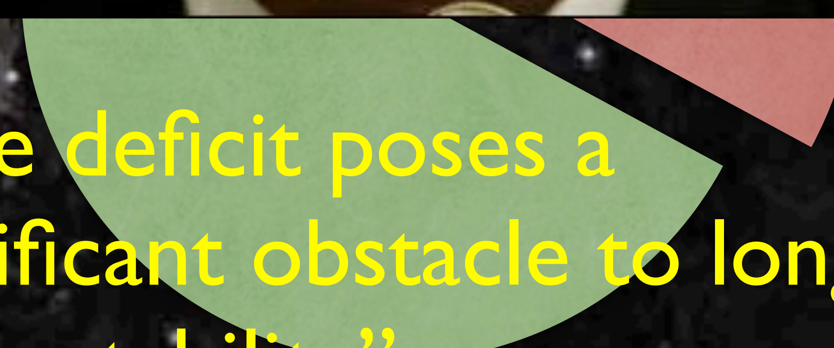
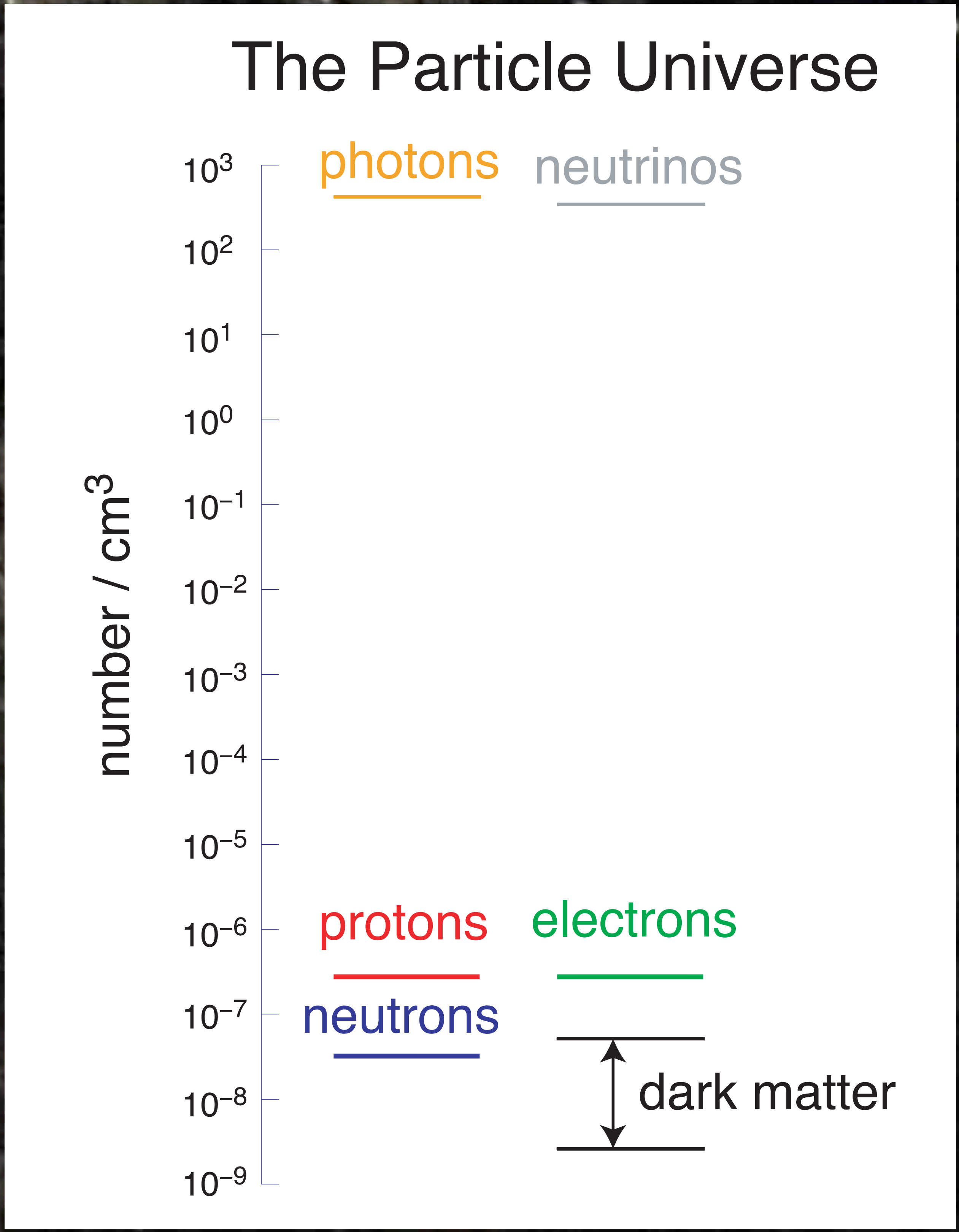


"The deficit poses a significant obstacle to long-term stability"

7

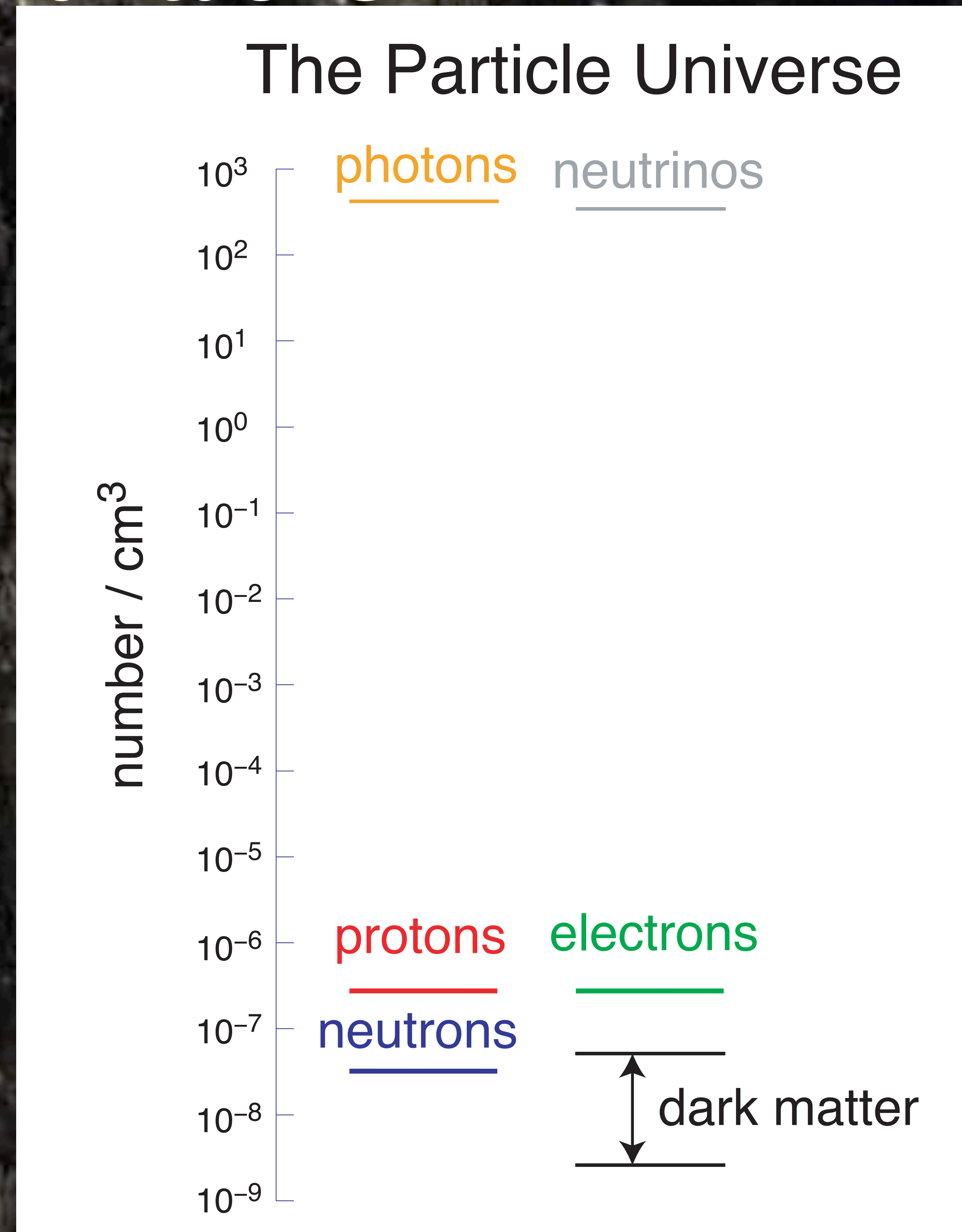
The Population



8

The Population

- Most ubiquitous particle is light (photons)



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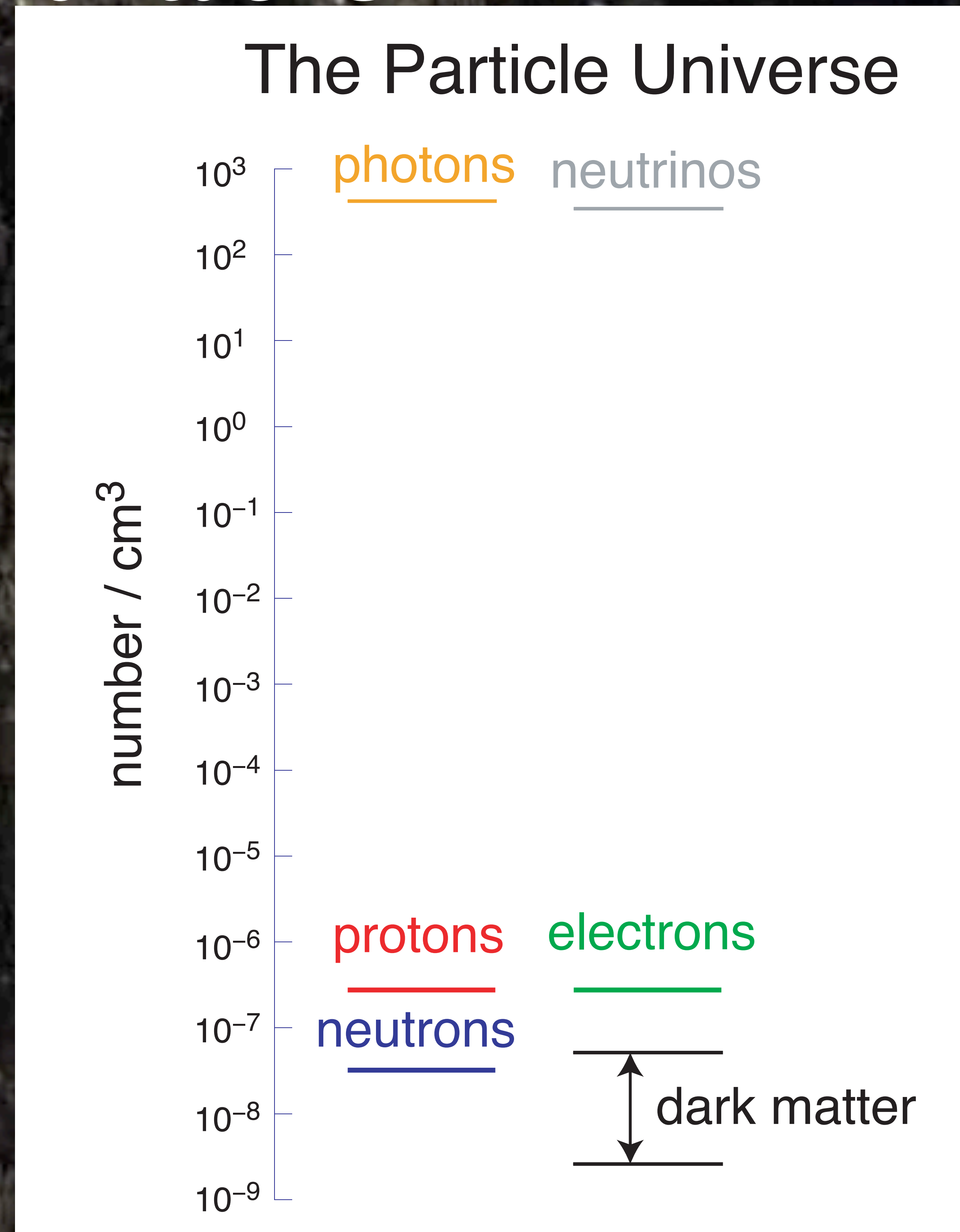

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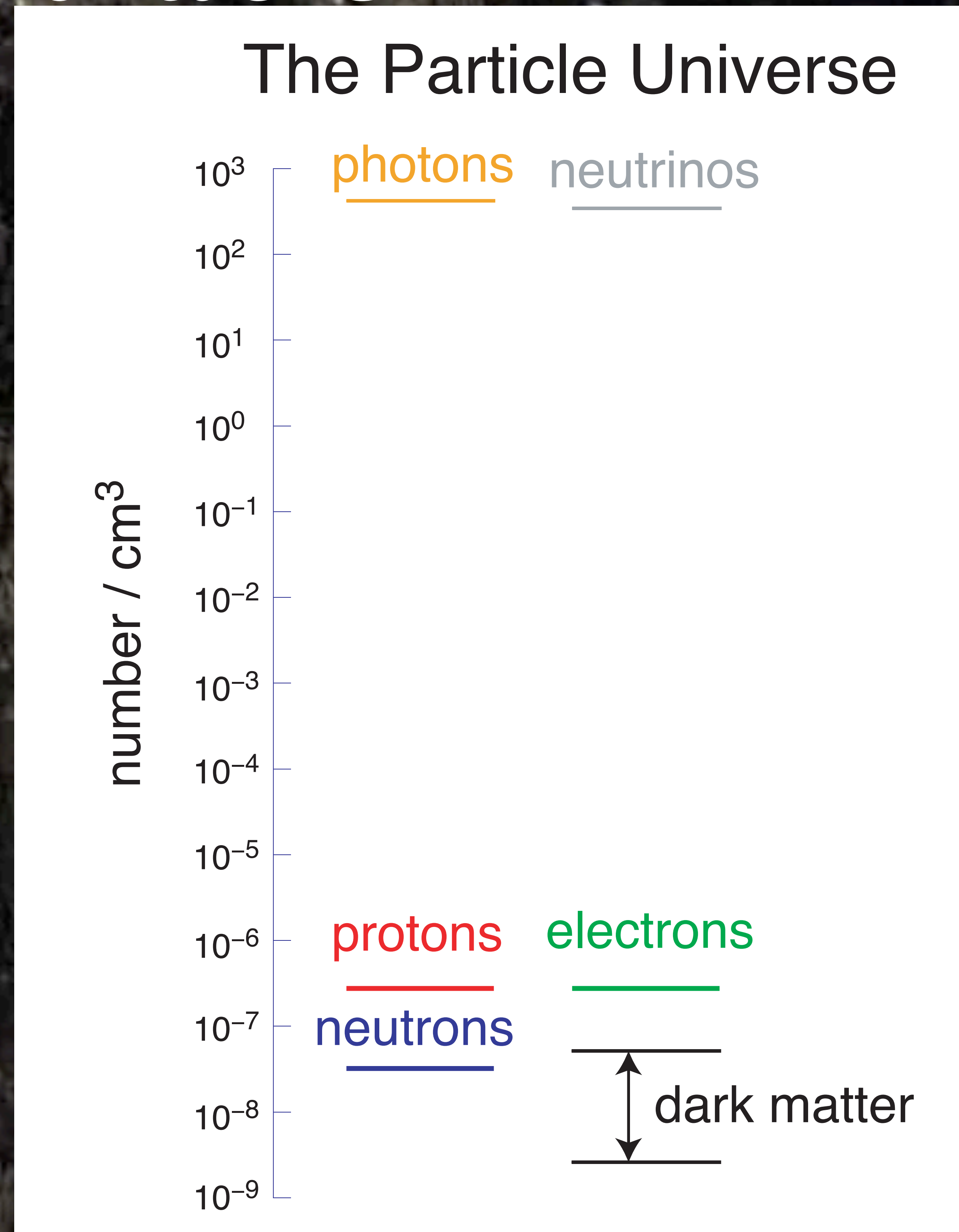
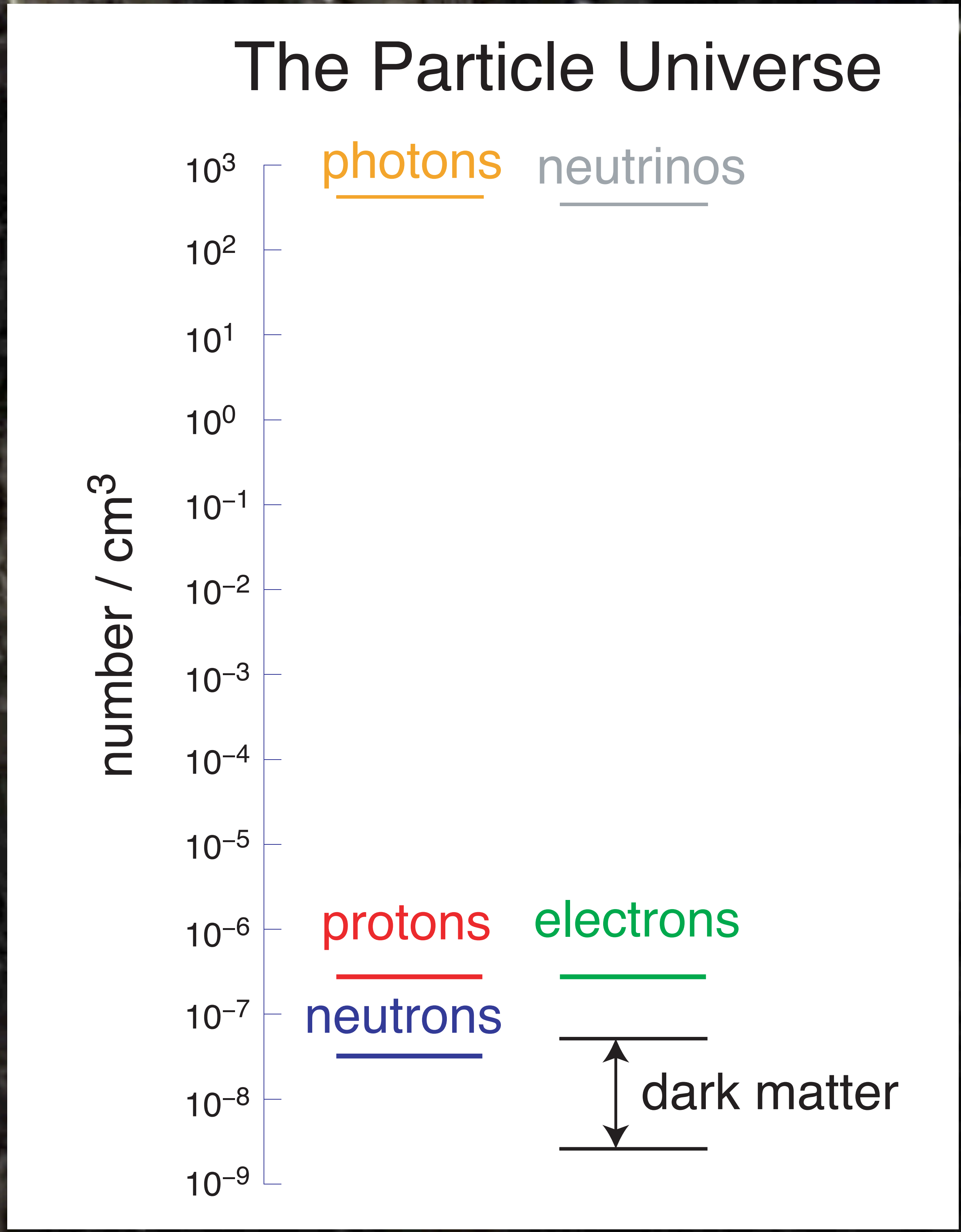


The Population

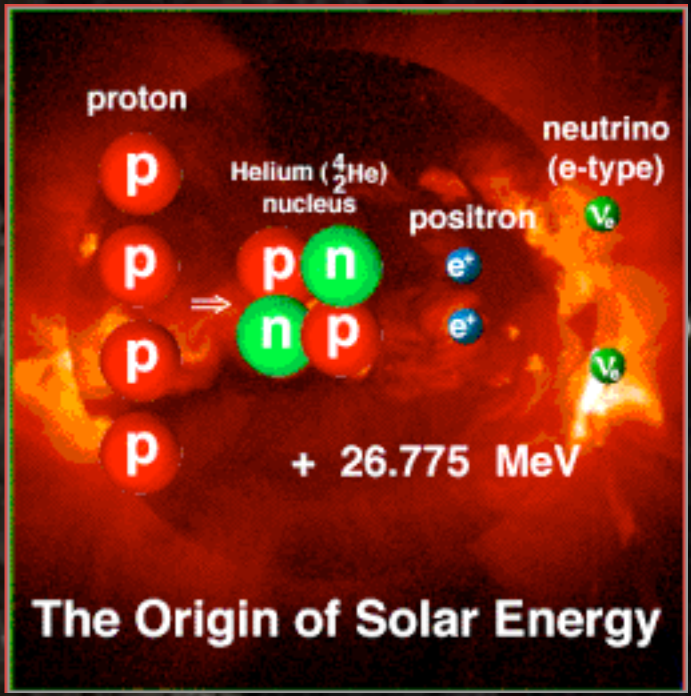
- Most ubiquitous particle is light (photons)
- Most ubiquitous matter particle is neutrinos
- Clearly we need to understand and use them to study the universe
- But neutrinos, dark matter all invisible!



8

Don’t be afraid of invisibles

Trillions of neutrinos go through our body every second coming from the Sun



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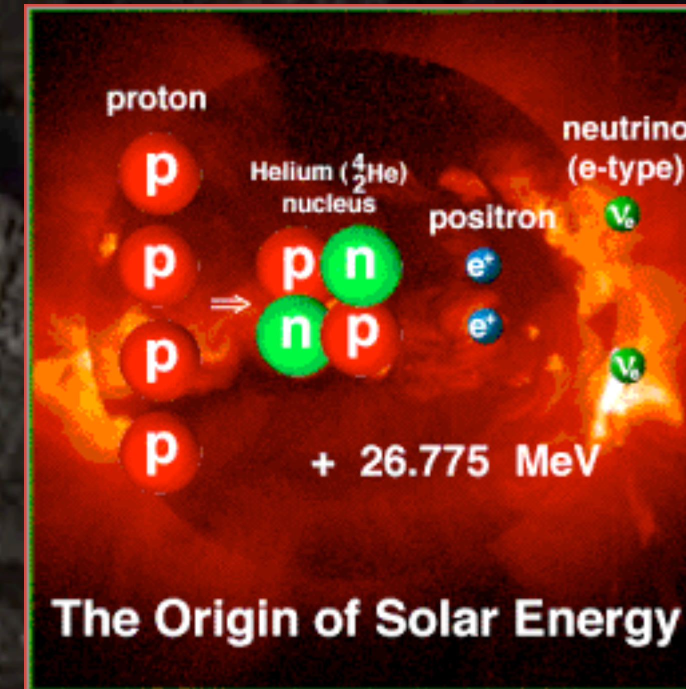

The Origin of Solar Energy

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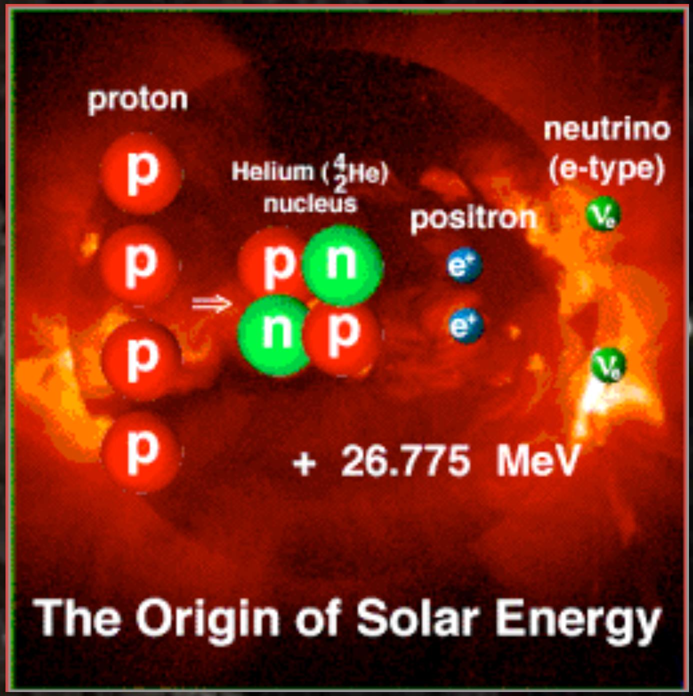
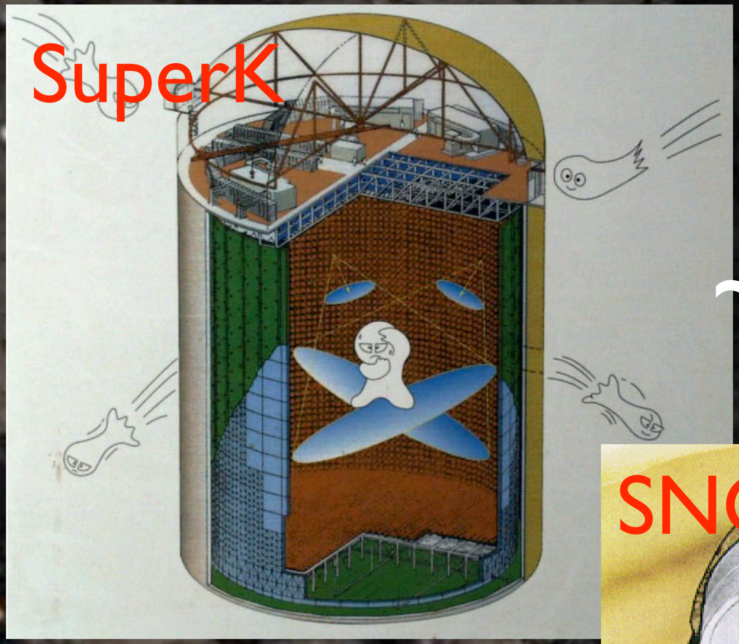
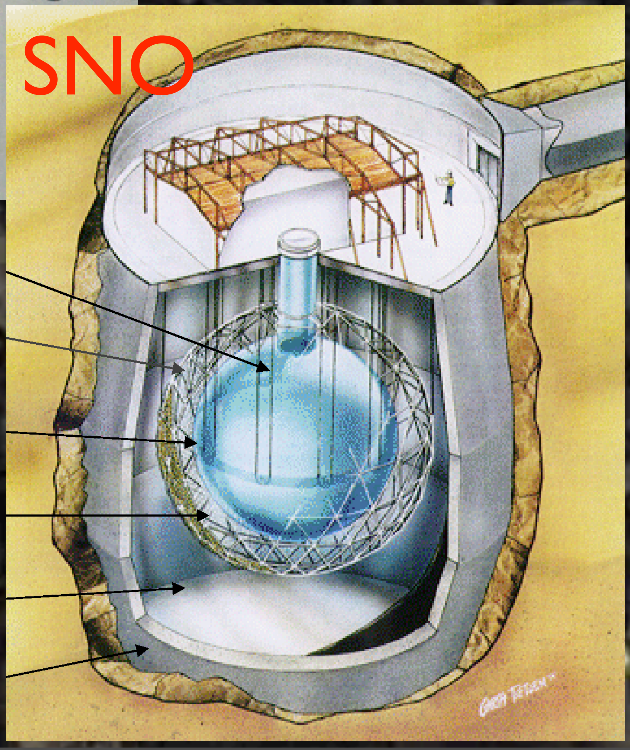




~100ft tall



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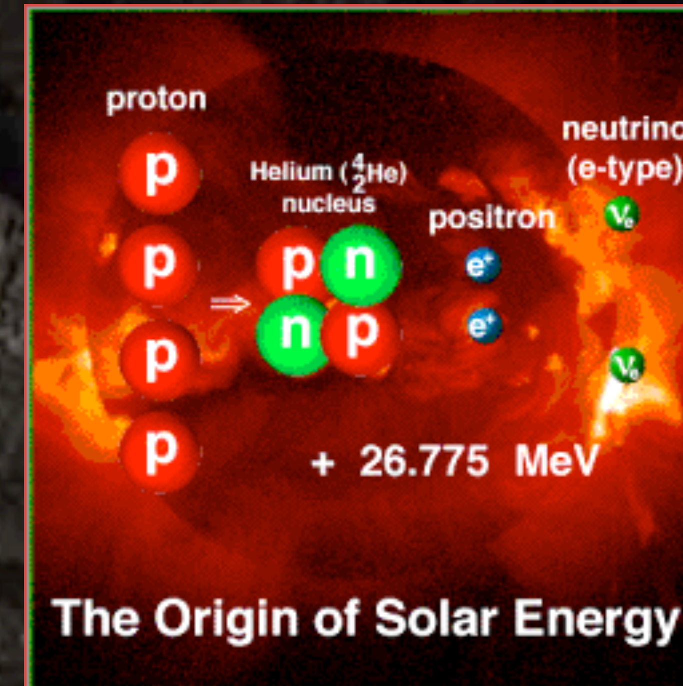

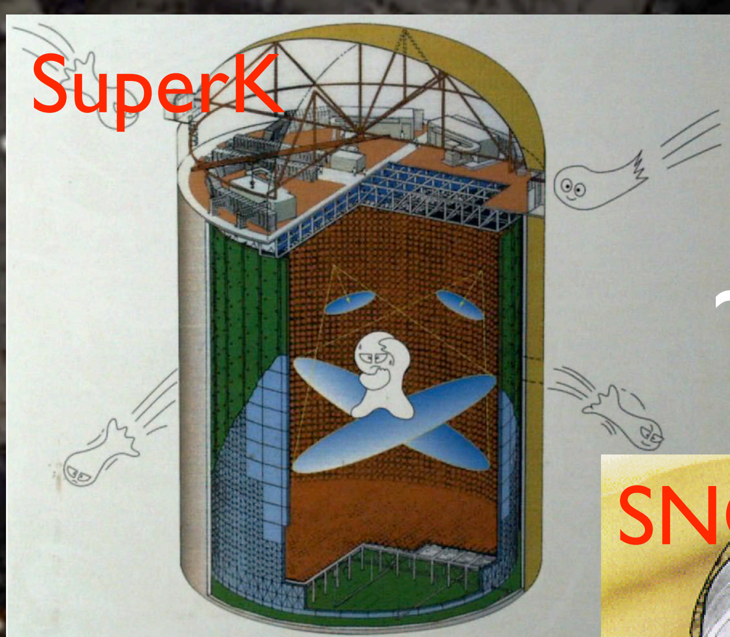

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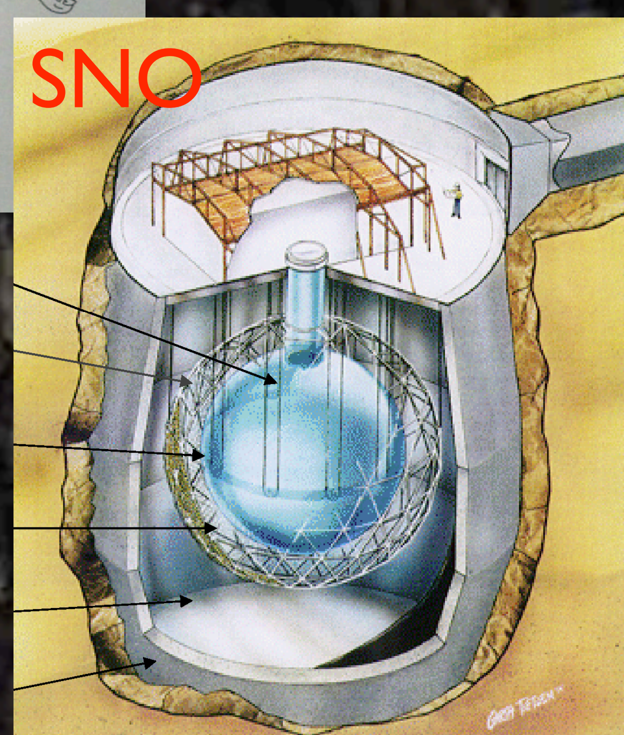

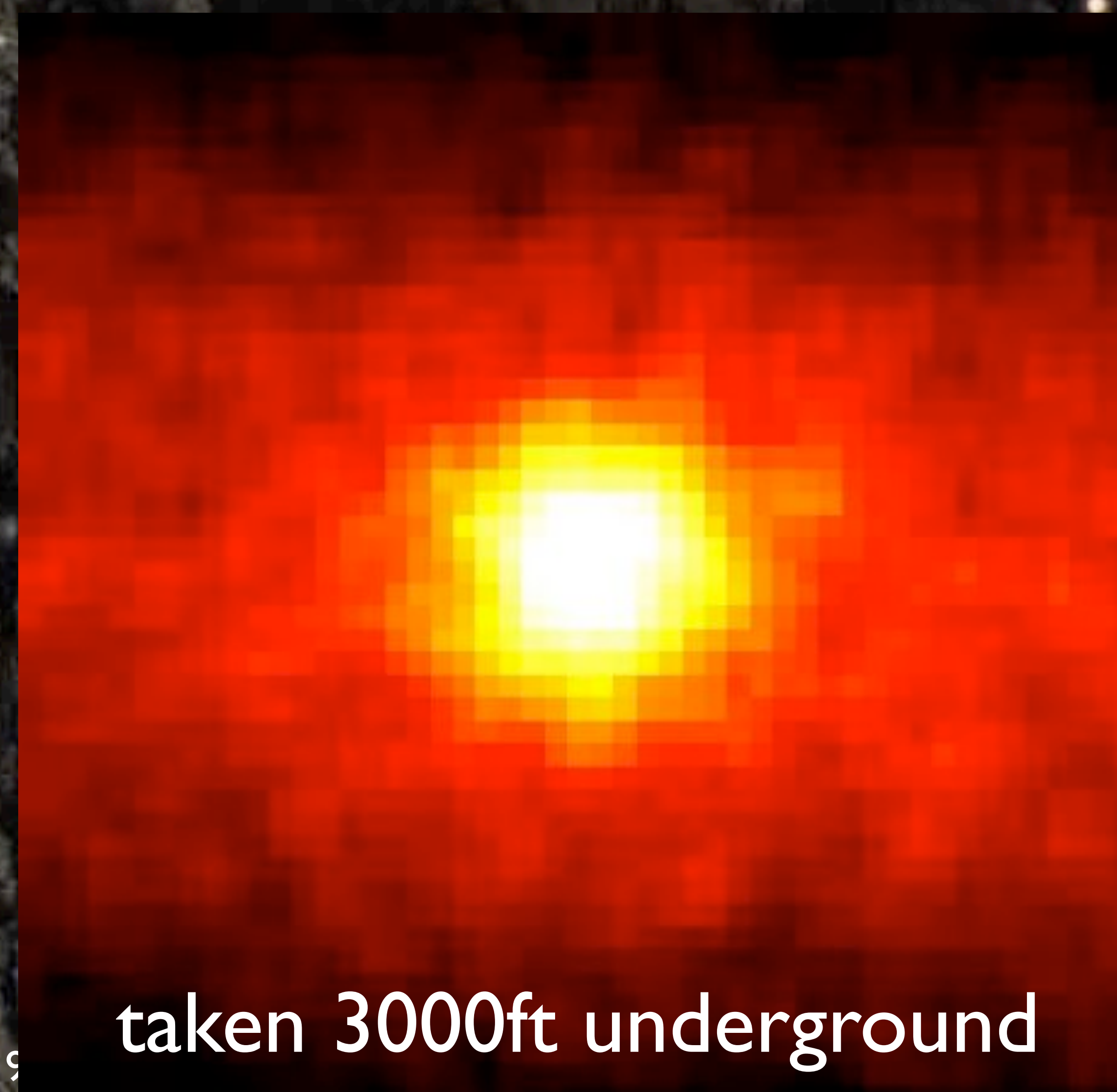

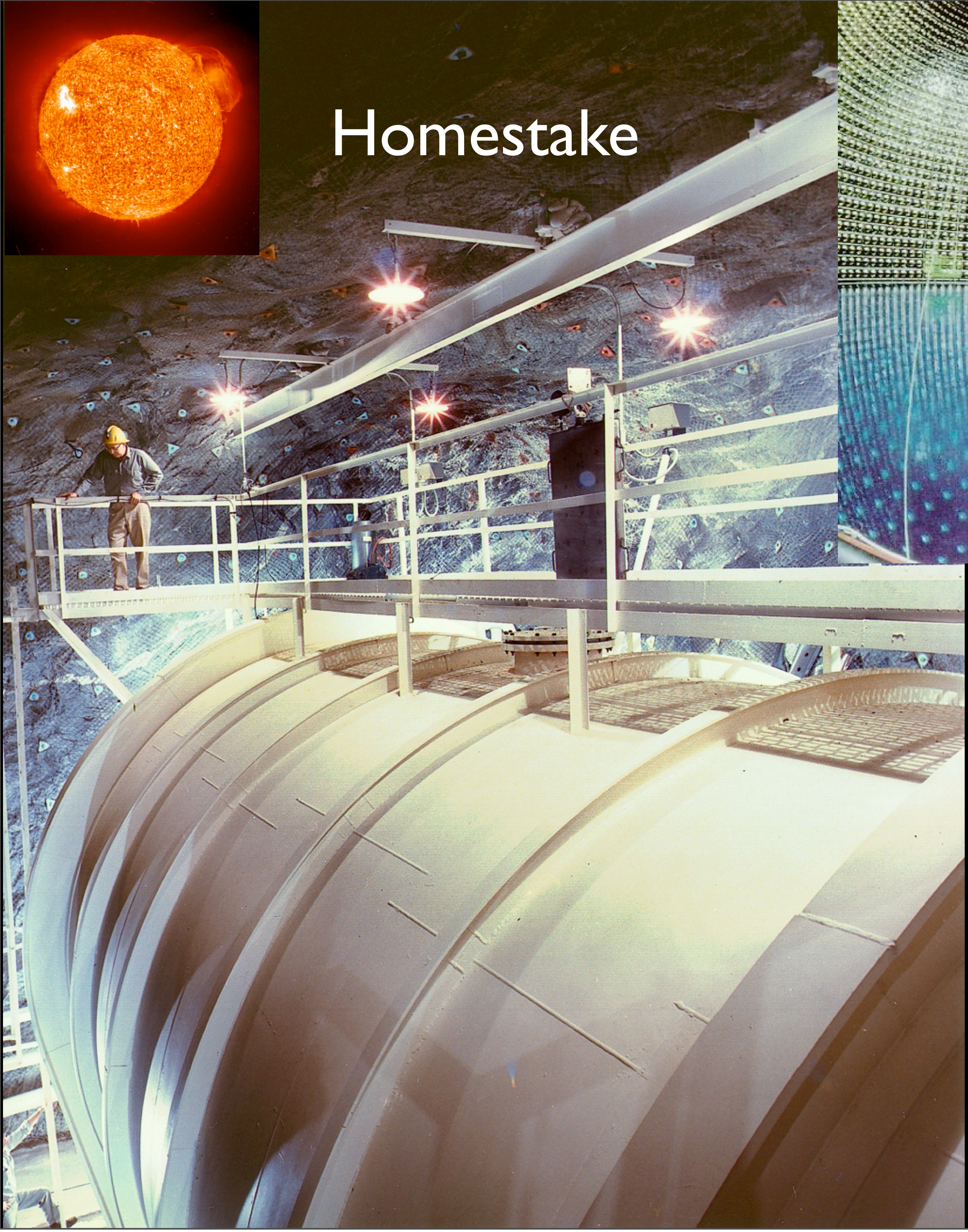

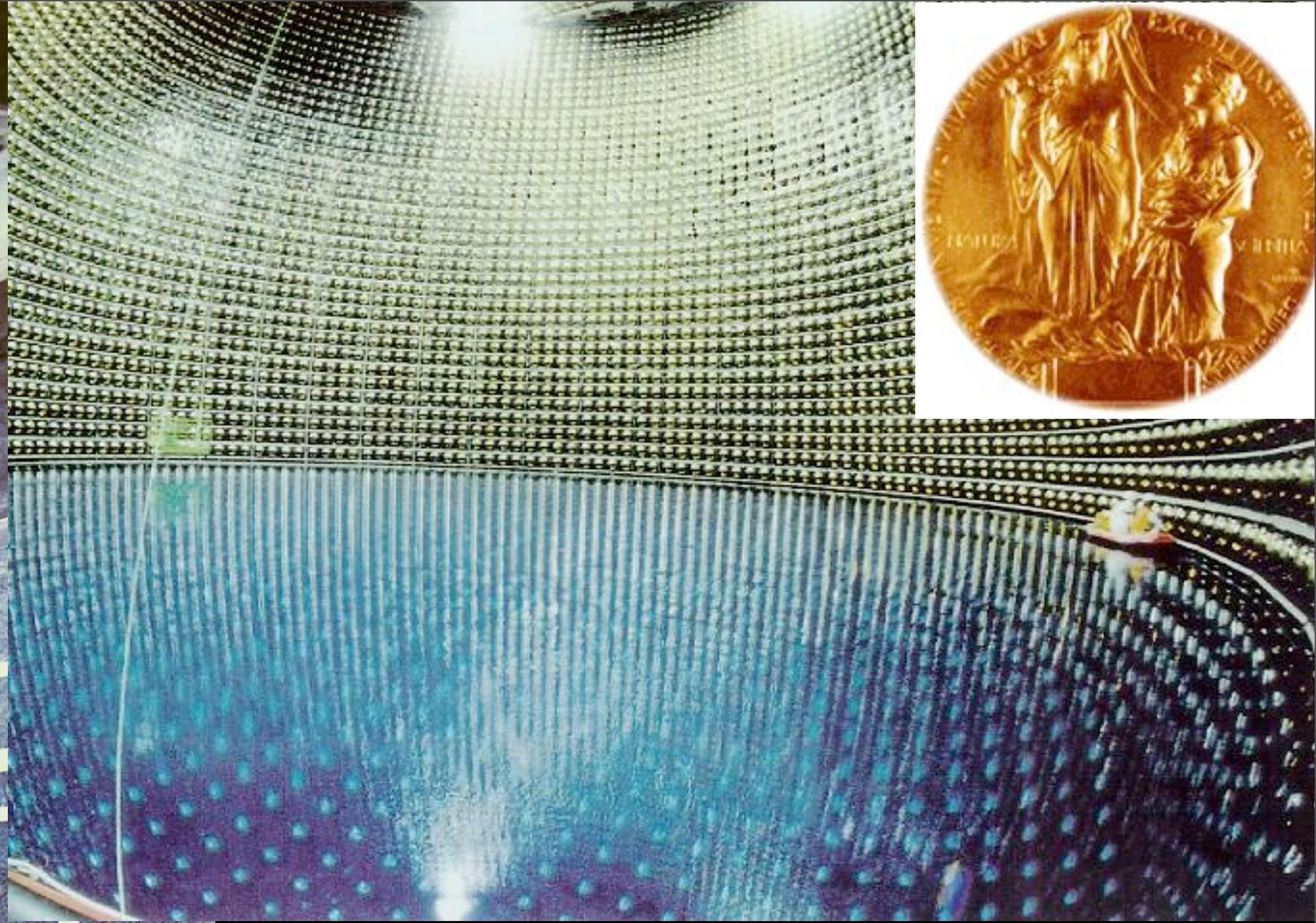

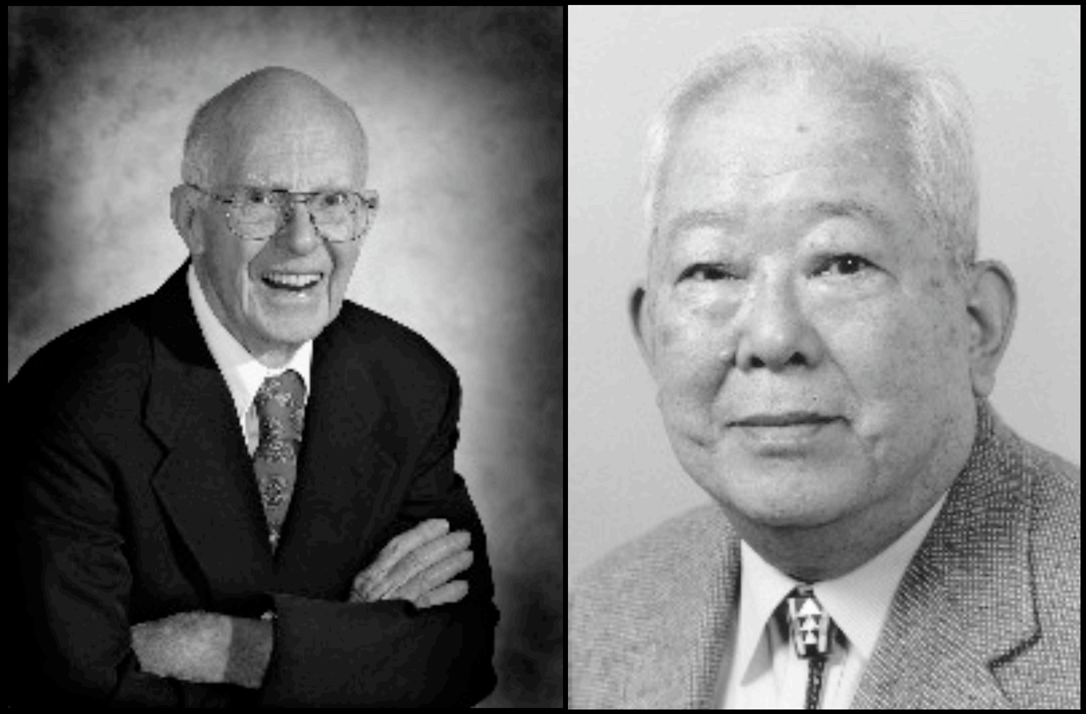

Nobel Prize in
Physics 2002

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DISNEY PRESENTS A PIXAR FILM
THE INCREDIBLES
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Big-Bang

Universe is expanding

- Approaching ambulance: higher key
- Moving-away ambulance: lower key
- Much the same way, moving-away stars: lower key (redder) in spectrum of light
- We see distant stars/ galaxies are redder

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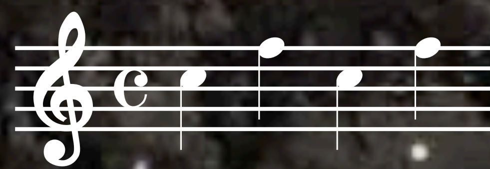

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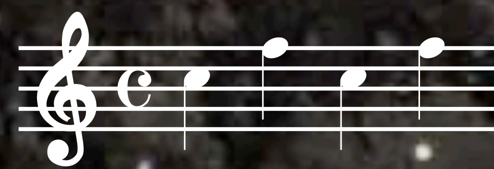

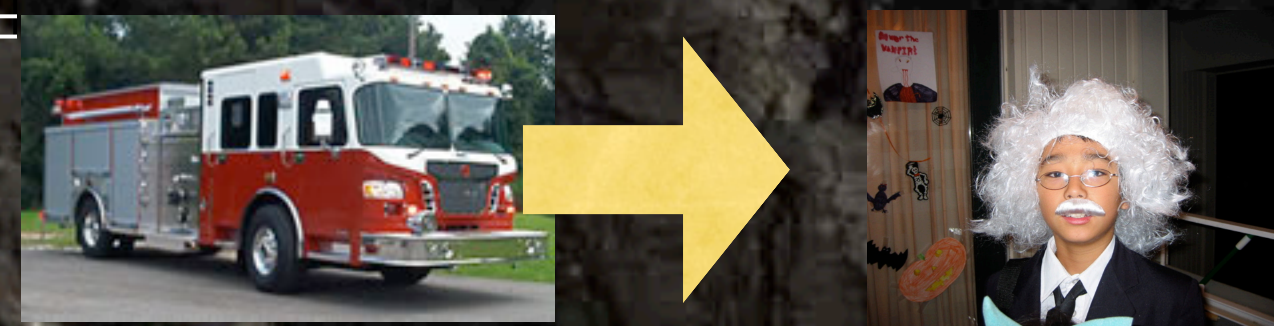

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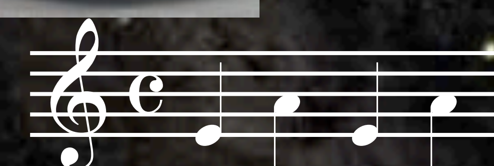

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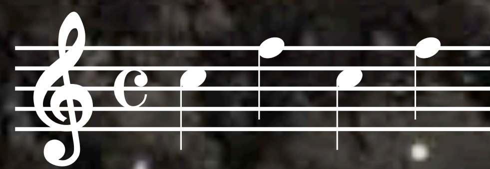

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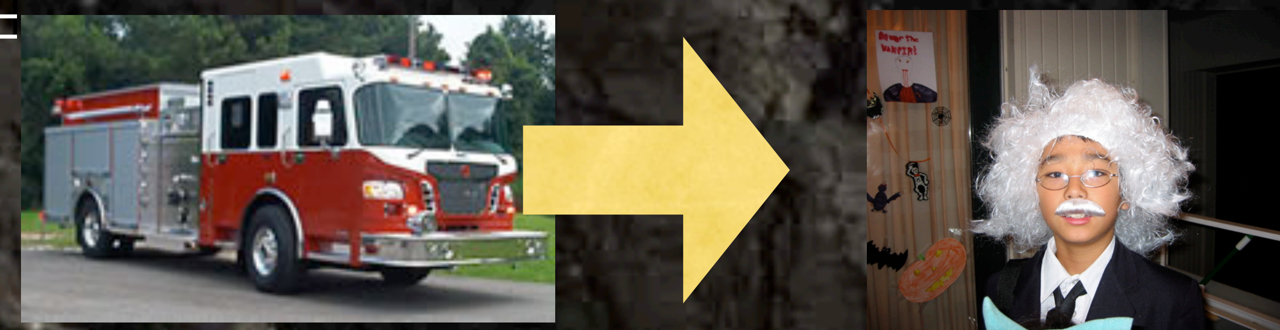

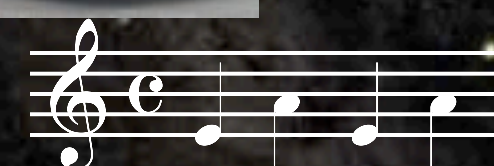

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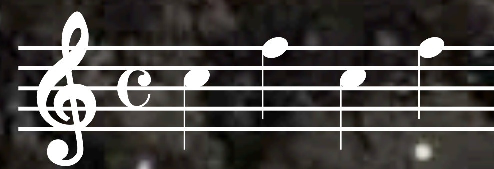

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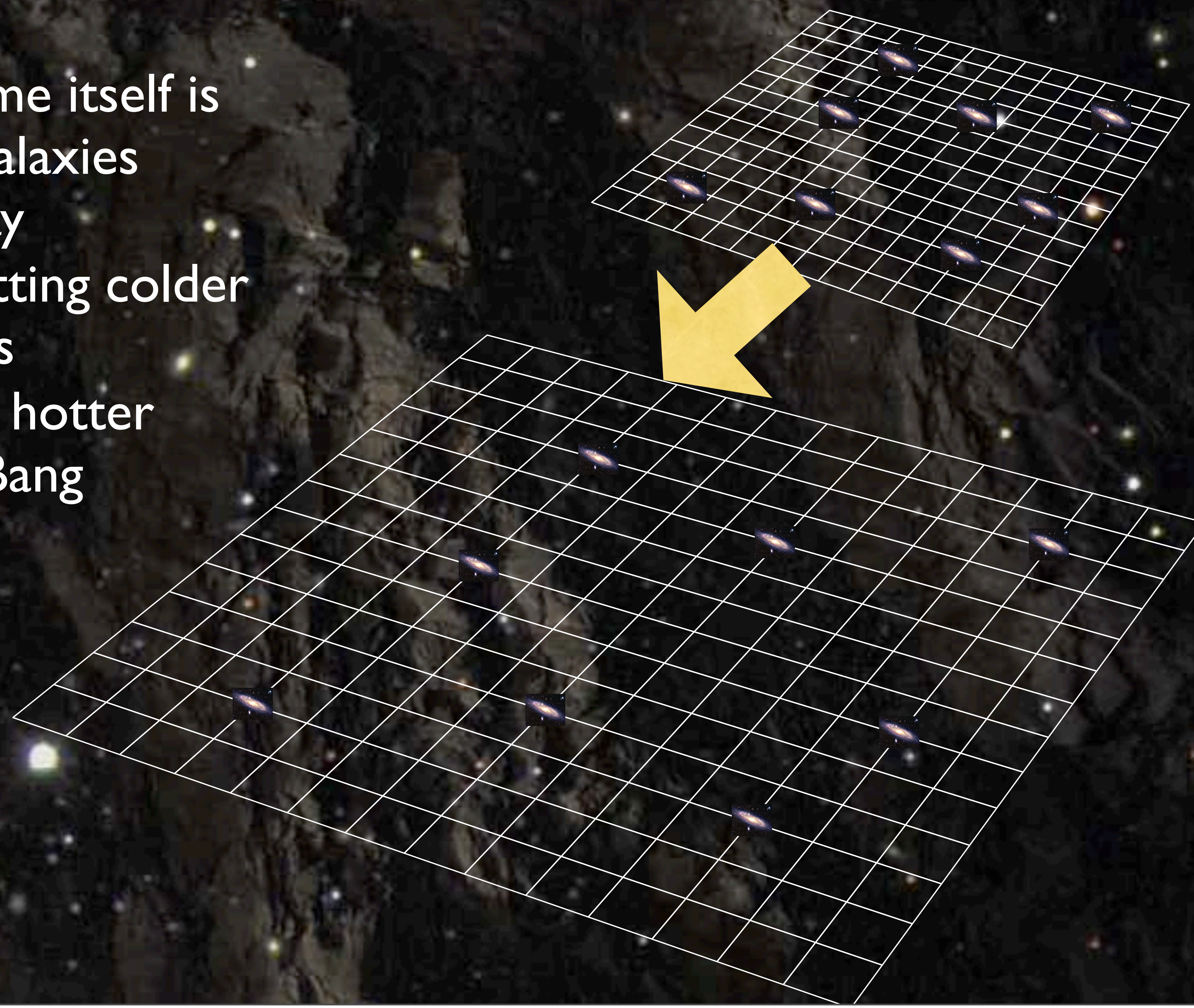
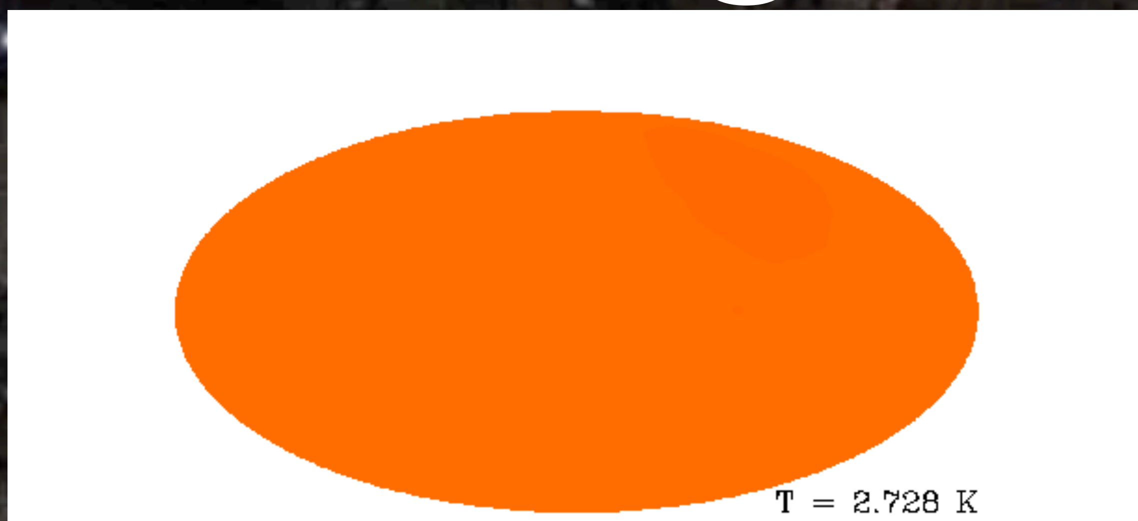
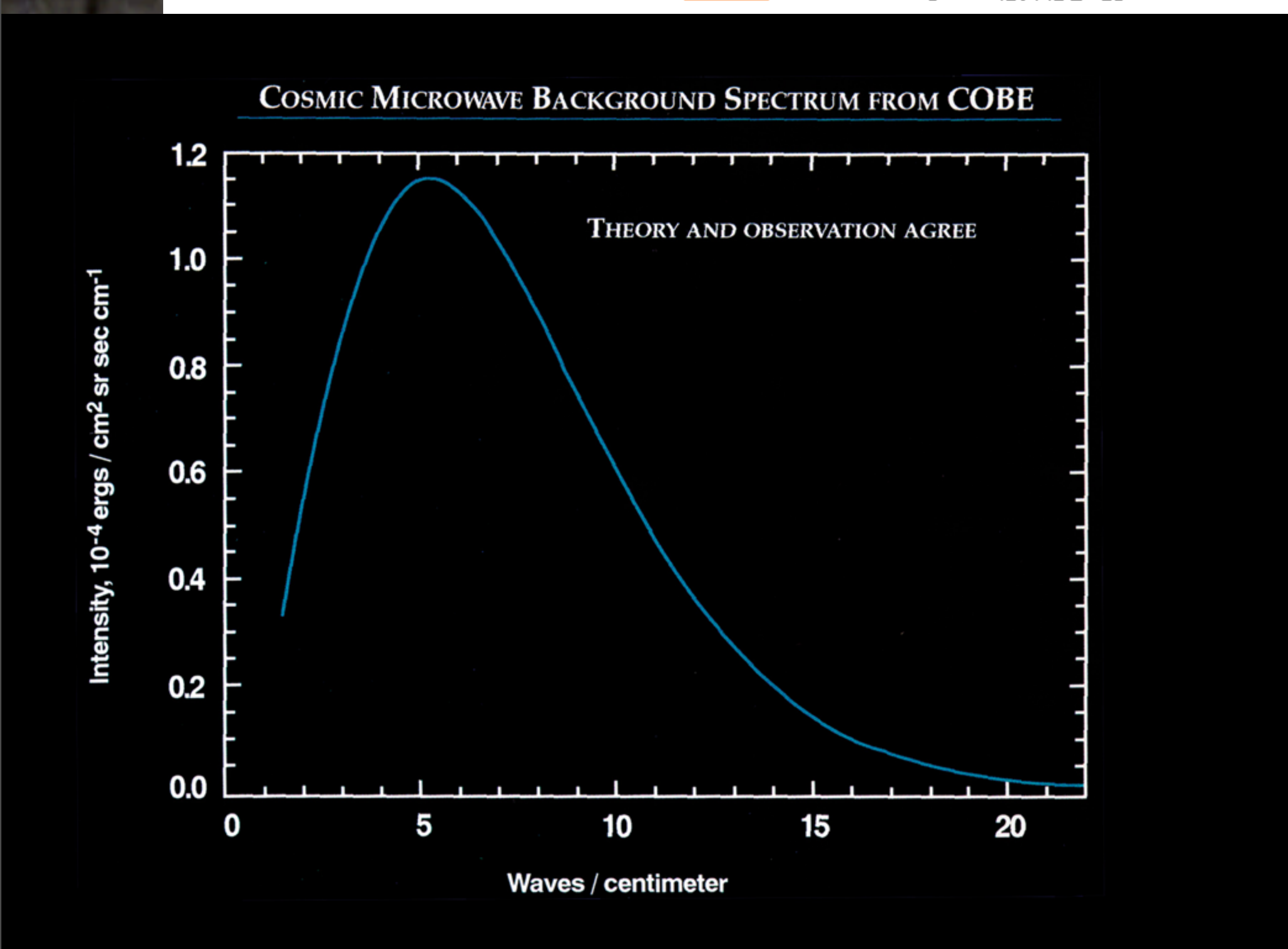
Expansion of Space

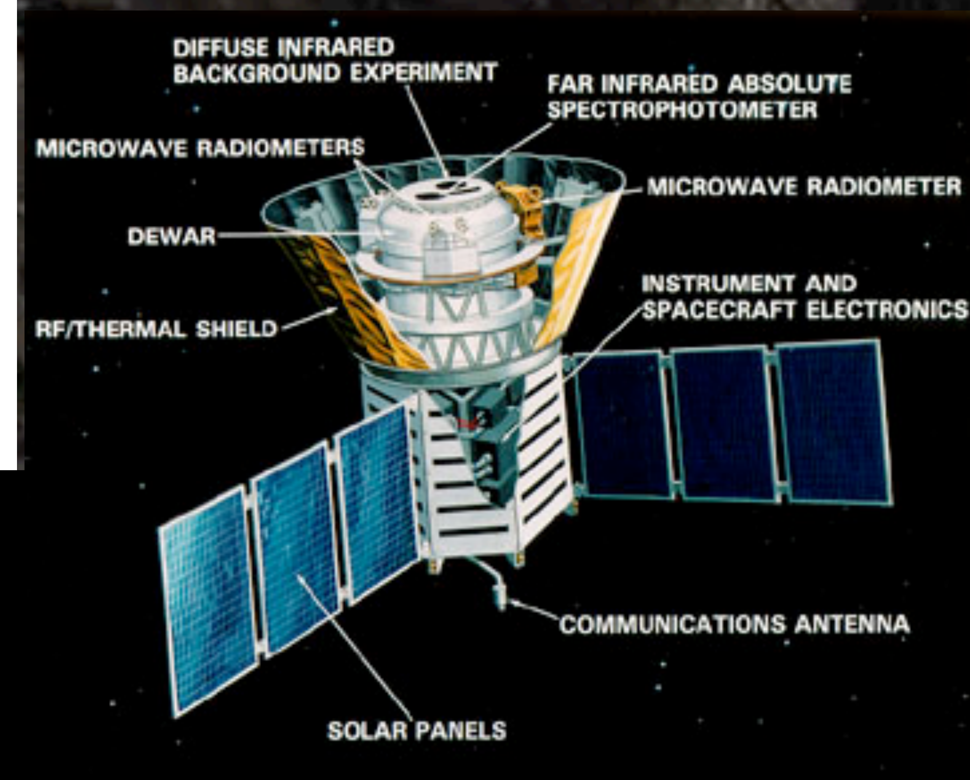
- The spacetime itself is stretching, galaxies dragged away
- Universe getting colder as it expands
- It was much hotter earlier: Big Bang



Afterglow of Big Bang

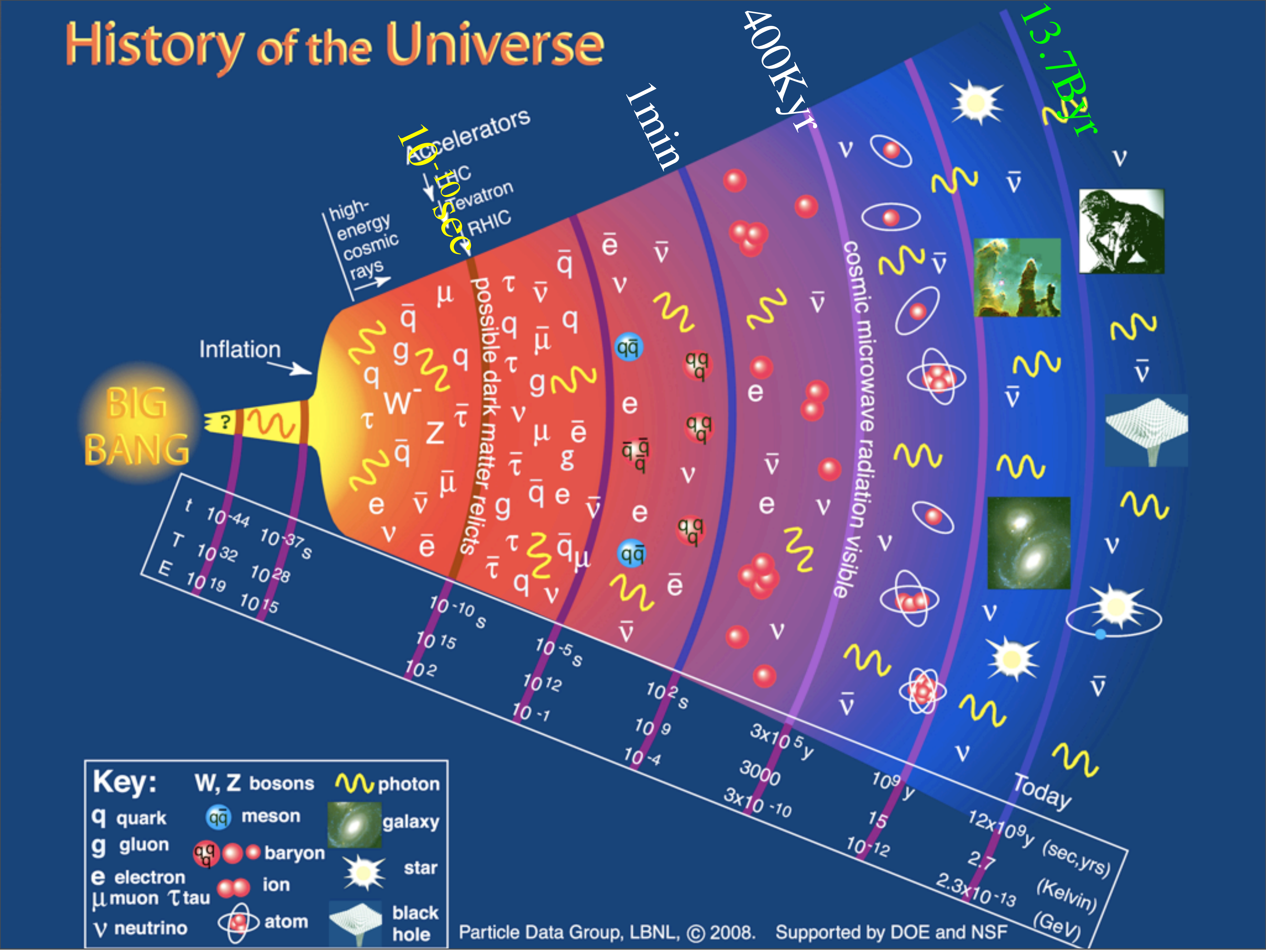


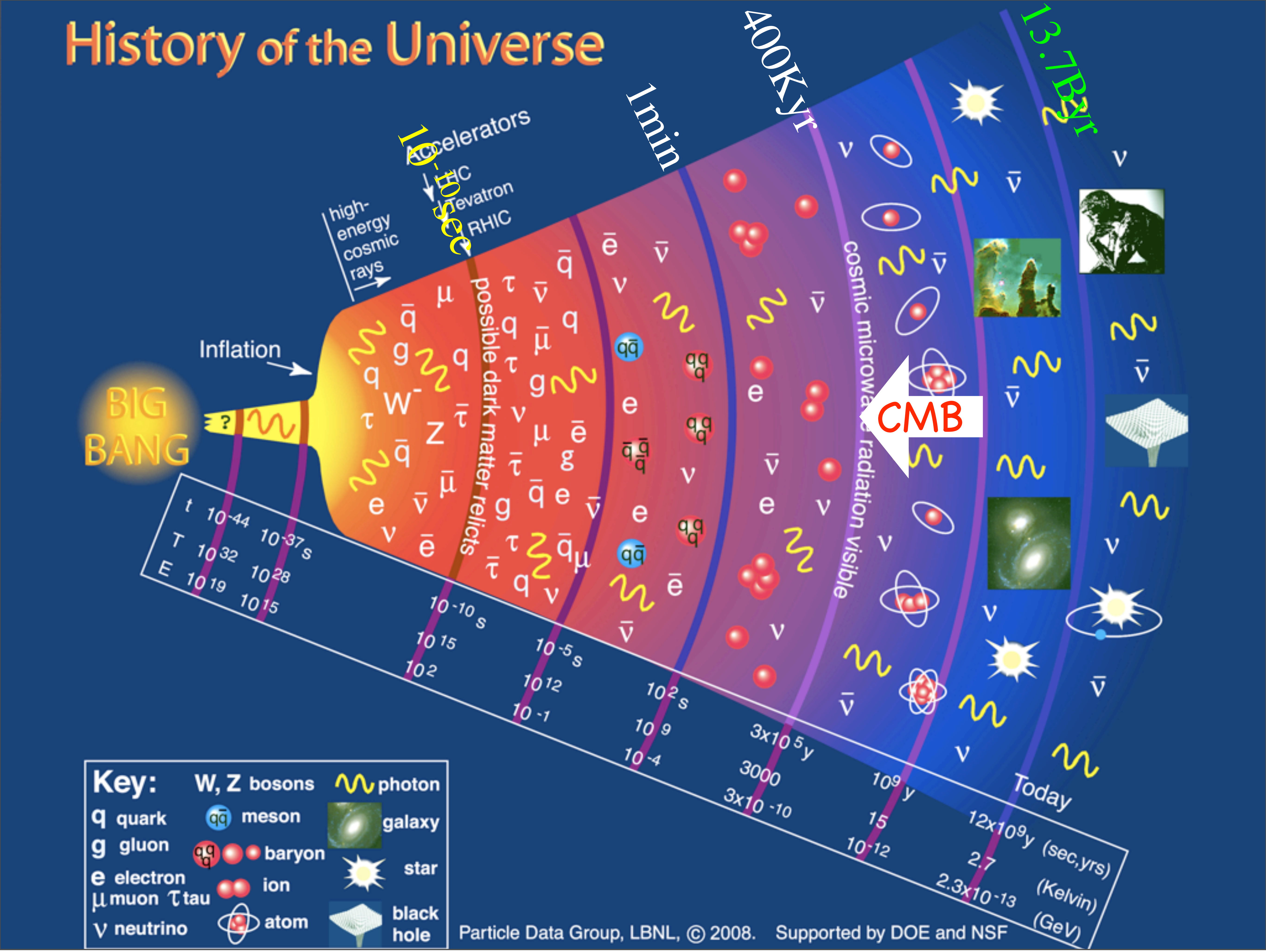




COBE satellite

Nobel Prize in Physics 2006


History of the Universe
BIG BANG
Inflation
high-energy cosmic rays
Accelerators
LHC
Tevatron
RHIC
10^{-10} sec
1min
400Kyr
13.7Byr
possible dark matter relicts
cosmic microwave radiation visible
t 10^{-44} 10^{-37} s
T 10^{32} 10^{28}
E 10^{19} 10^{15}
10^{-10} s
10^{15}
10^{2}
10^{-5} s
10^{12}
10^{-1}
10^{2} s
10^{9}
10^{-4}
3×10^{5} y
3000
3×10^{-10}
10^{9} y
15
10^{-12}
Today
12×10^{9} y (sec,yrs)
2.7 (Kelvin)
2.3×10^{-13} (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF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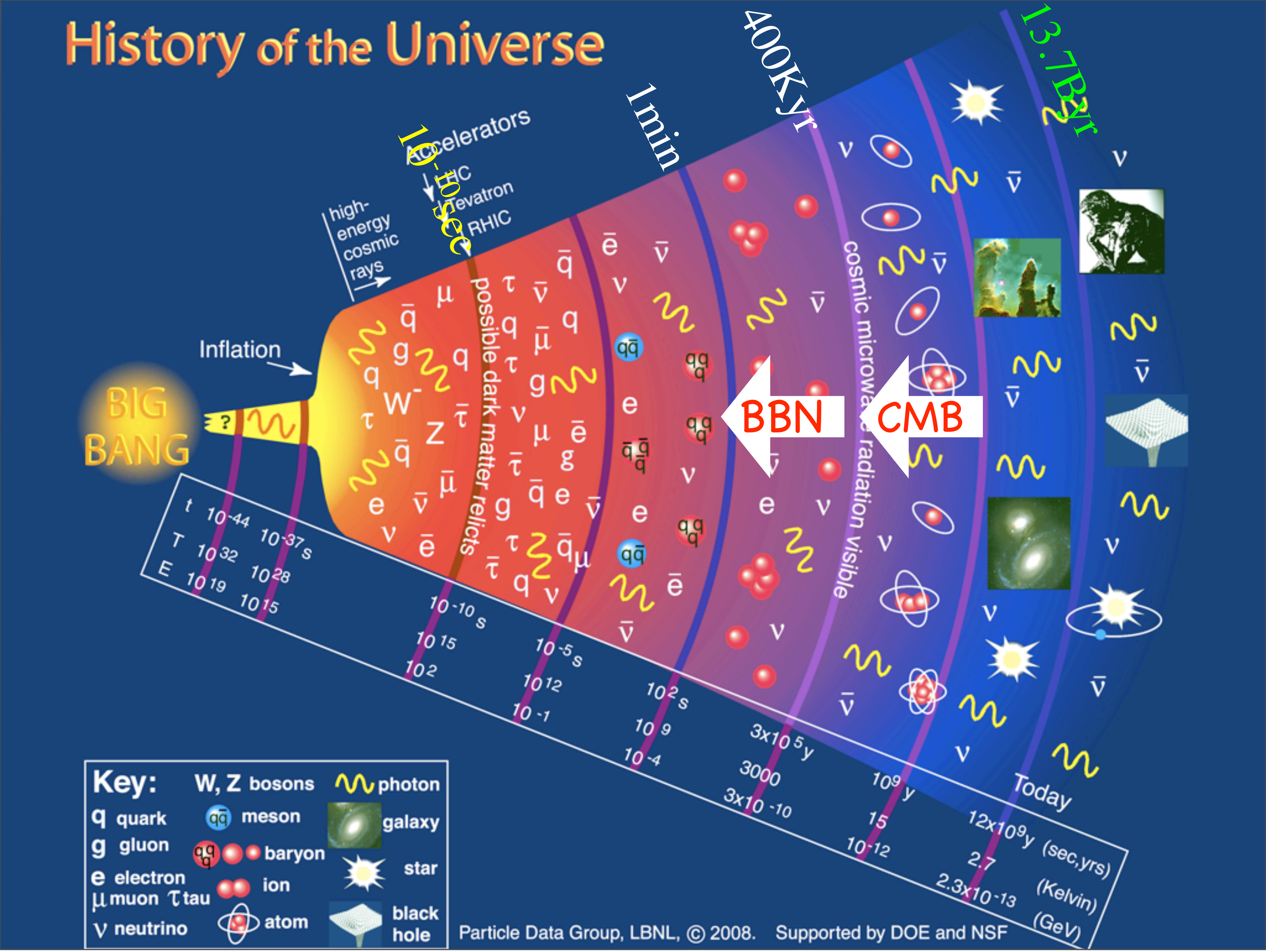
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF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W, Z bosons
photon
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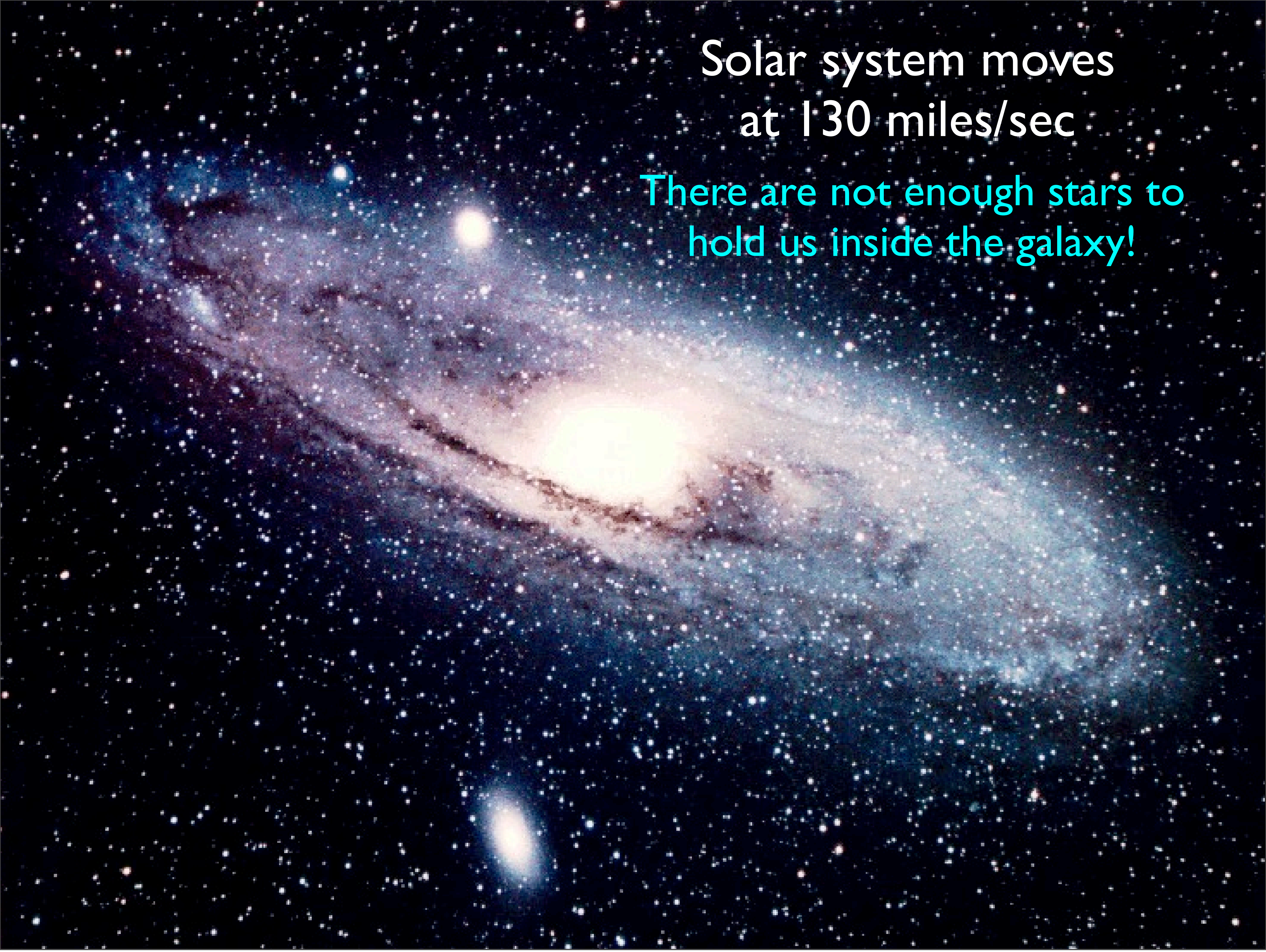
ν neutrino
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

Cosmic Questions for DUSEL

- What is the Universe made of?
- What is Dark Matter?
- Did neutrinos form galaxies?
- Where did the Anti-Matter go?
- Where did we come from?


Dark Matter


Solar system moves
at 130 miles/sec
There are not enough stars to
hold us inside the galaxy!

Solar system moves at 130 miles/sec

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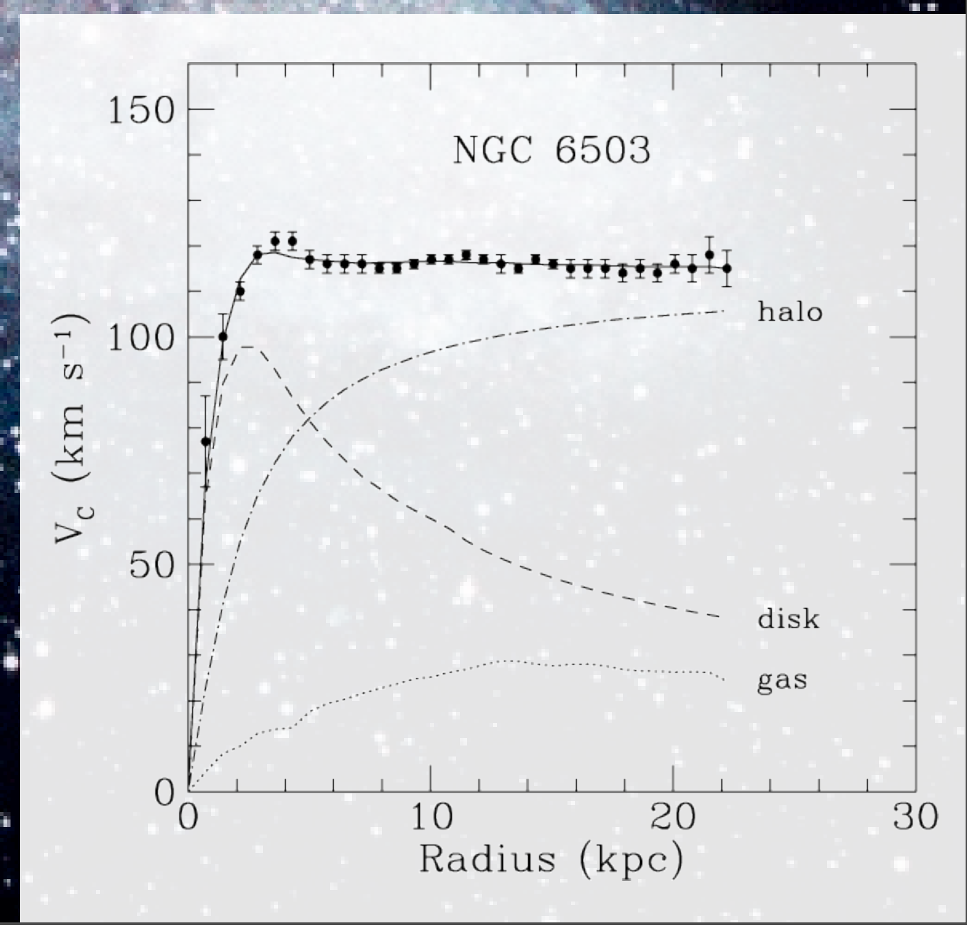

Solar system moves at 130 miles/sec

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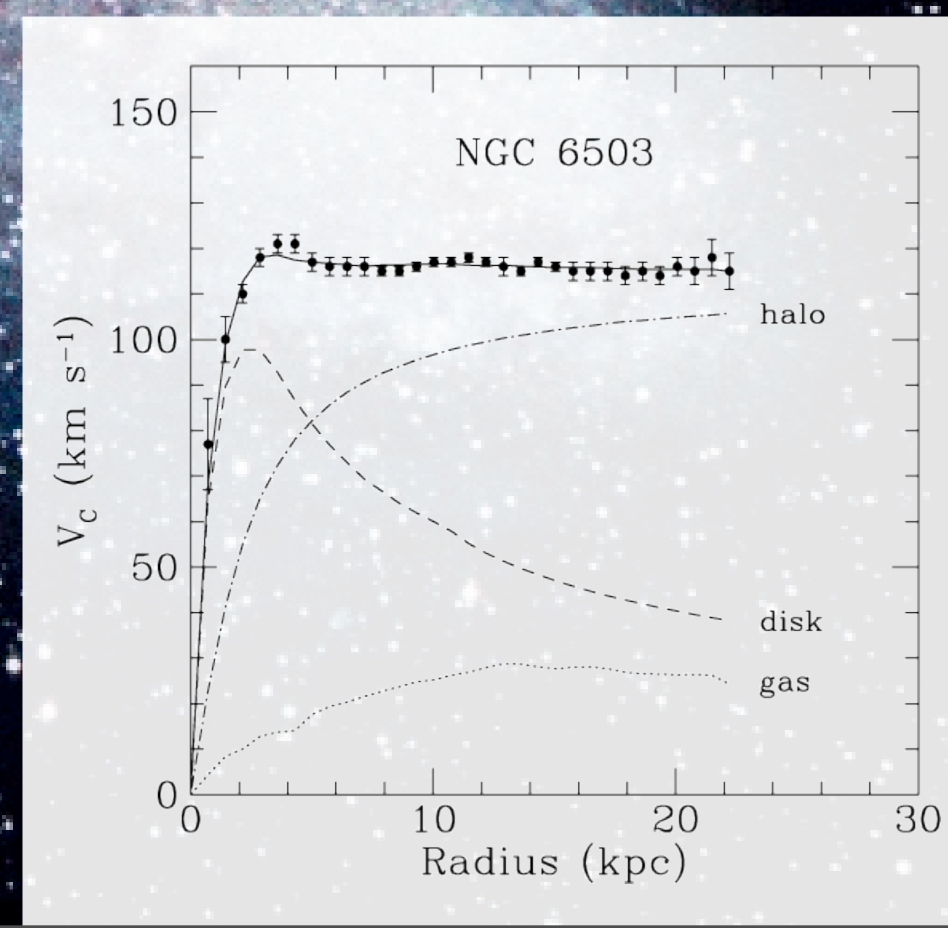
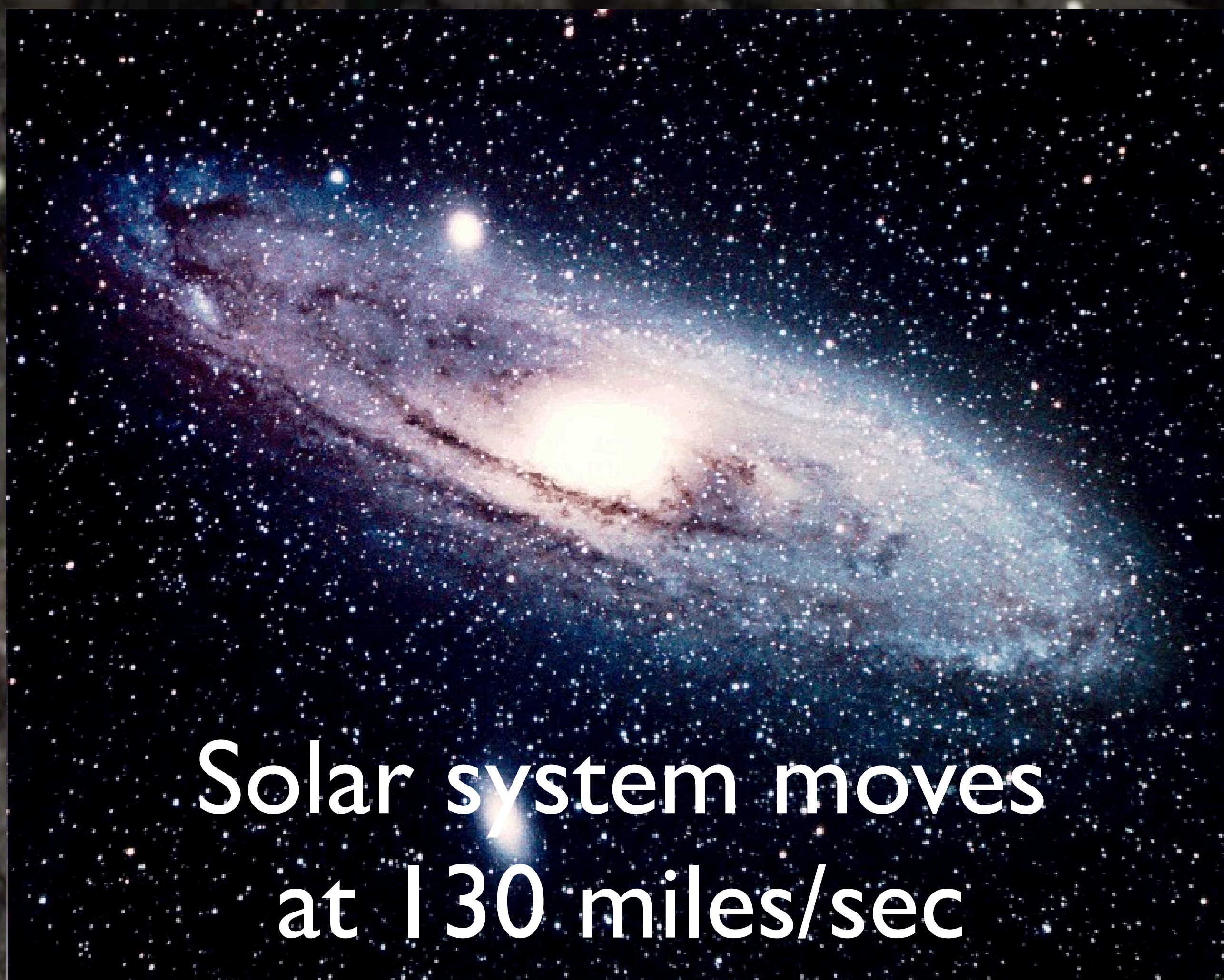
Something else we can't see is keeping us inside the galaxy



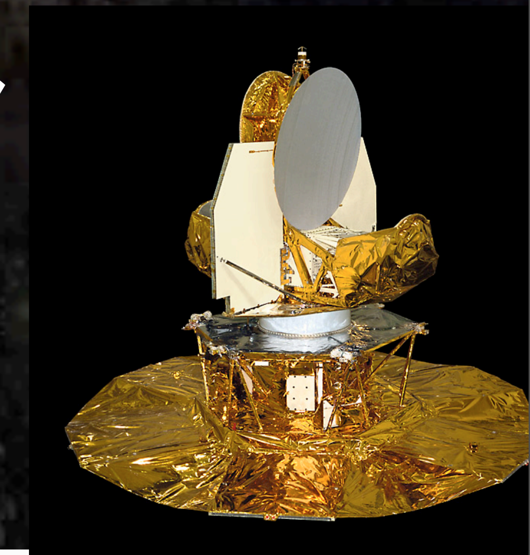
More Evidence for Dark Matter

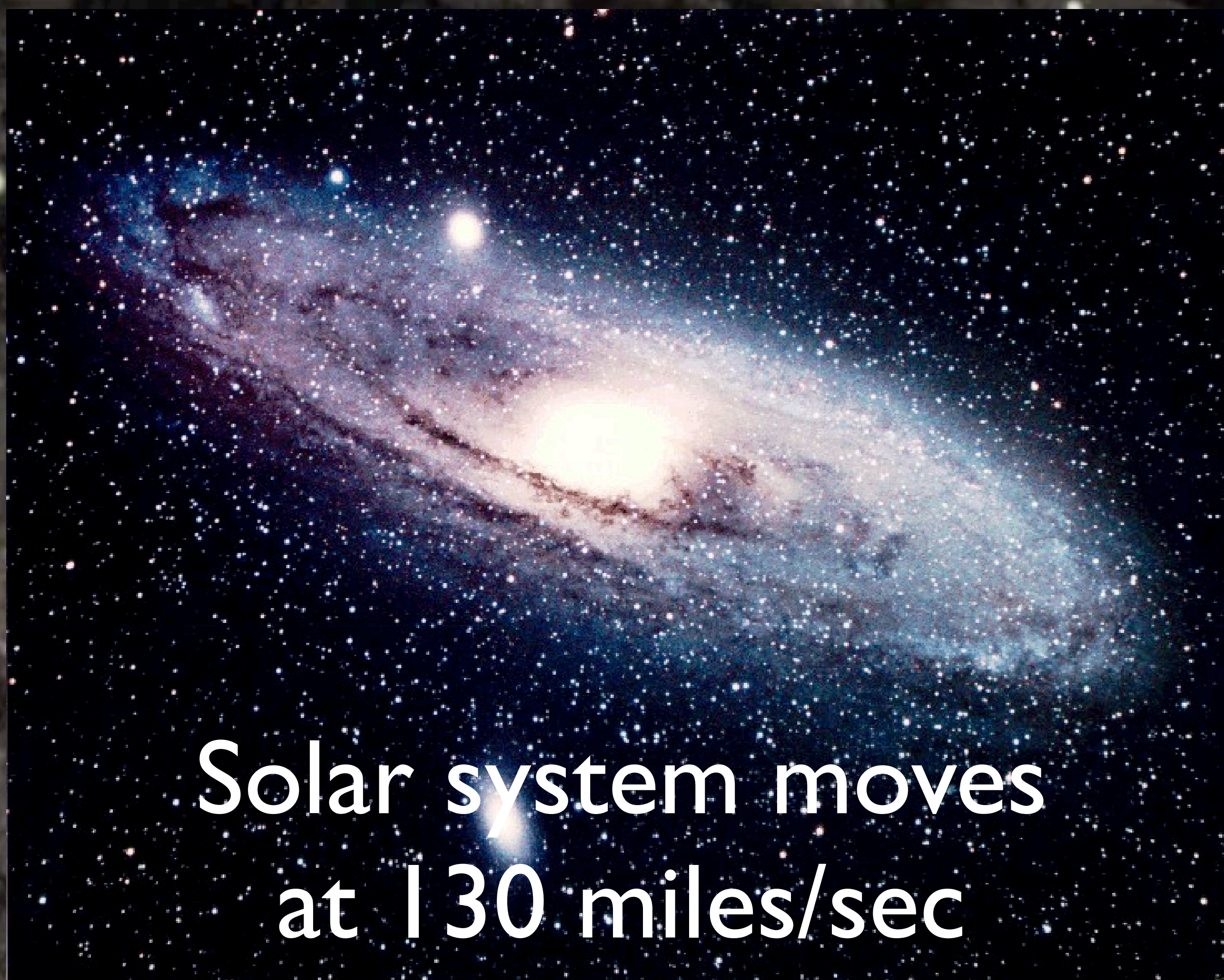


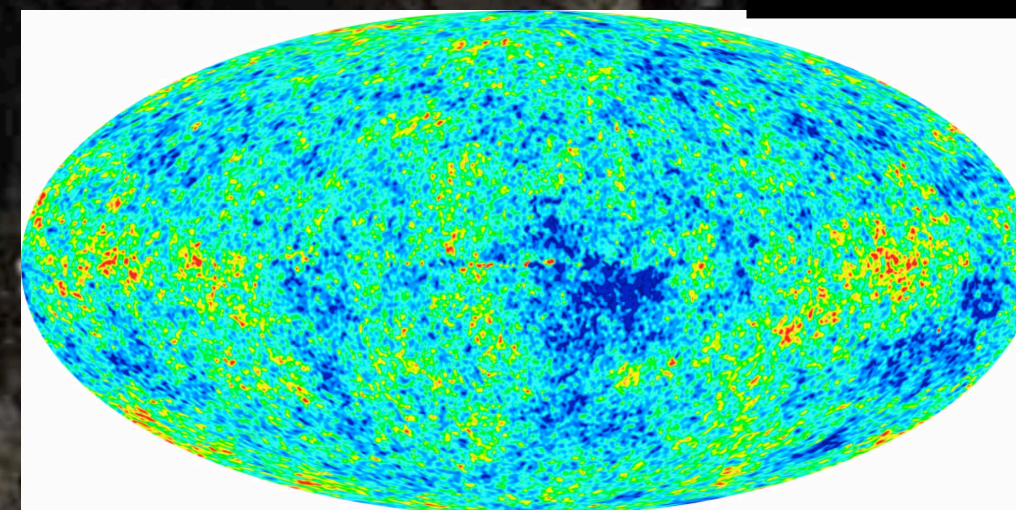
There are not enough stars to hold us inside the galaxy!

X

More Evidence for Dark Matter







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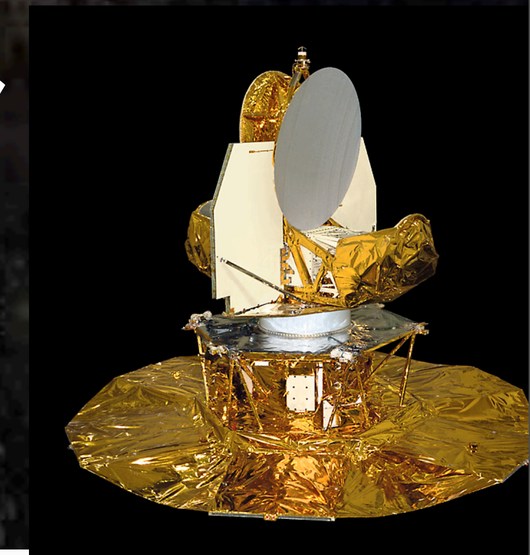
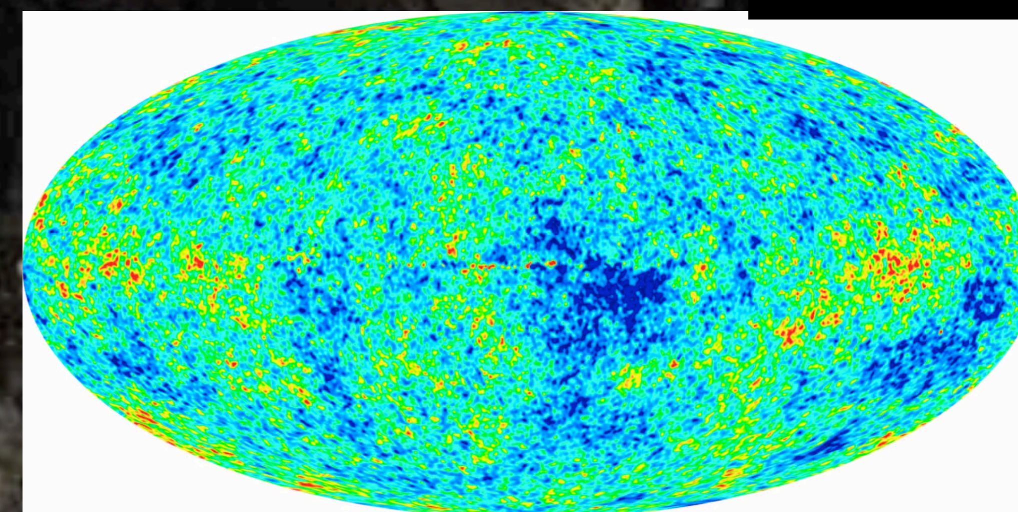
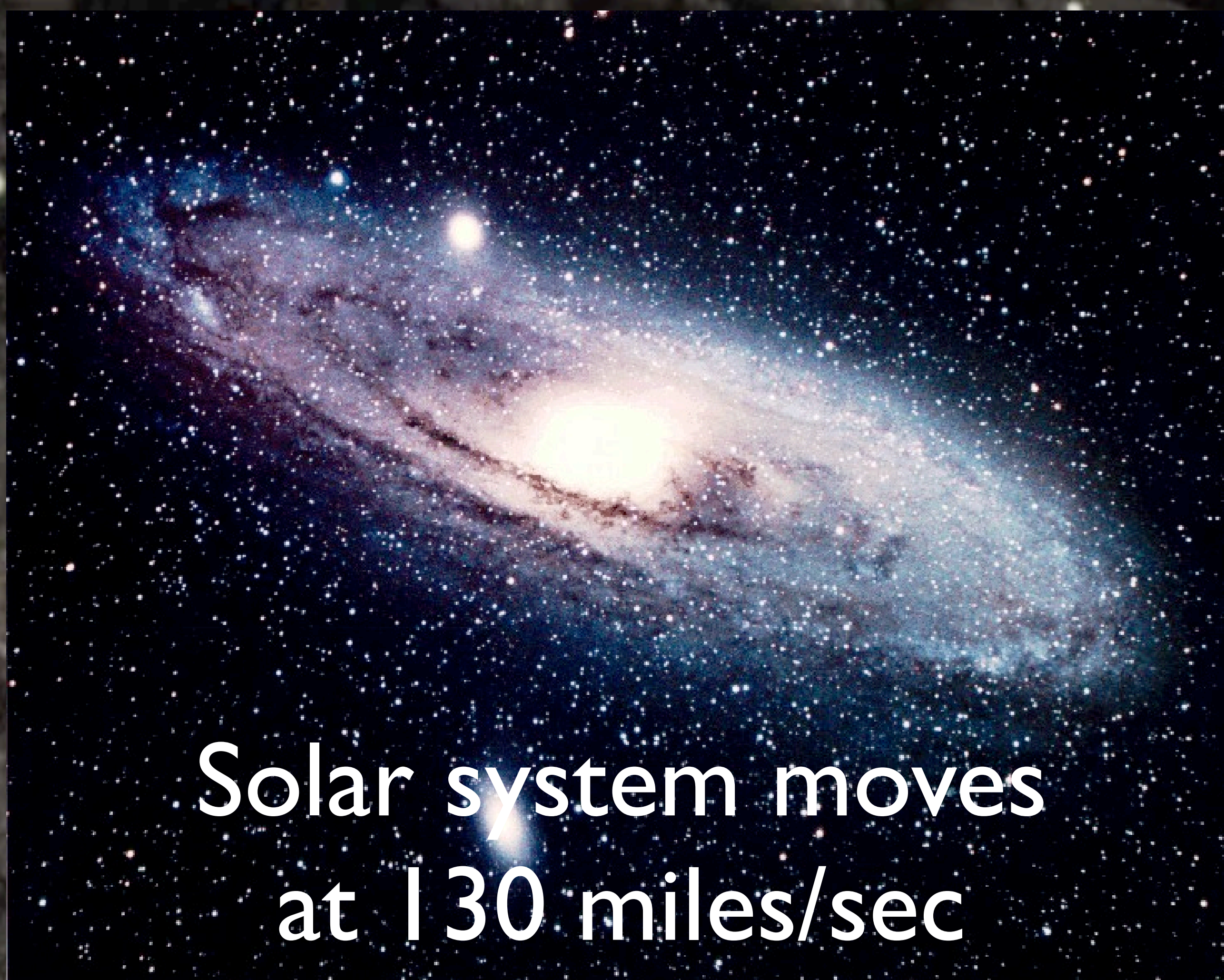




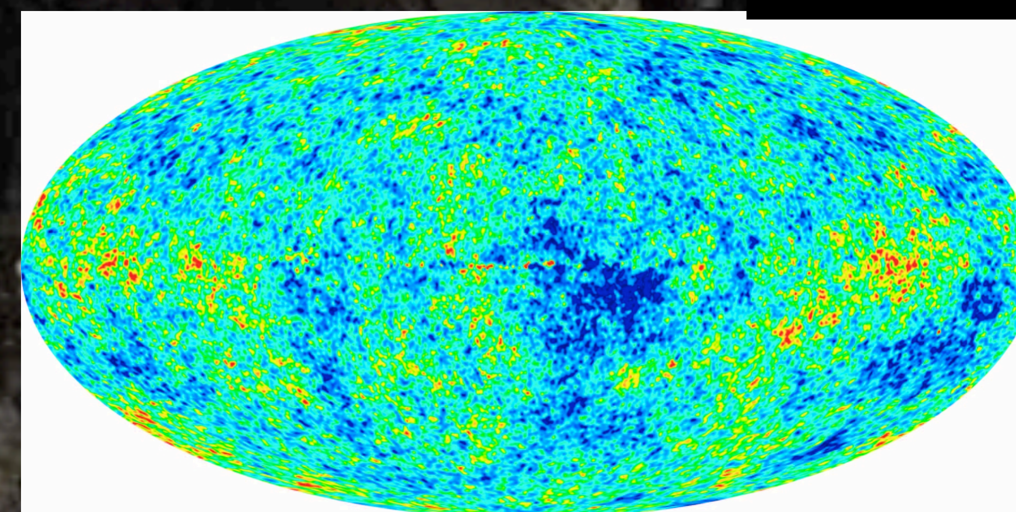


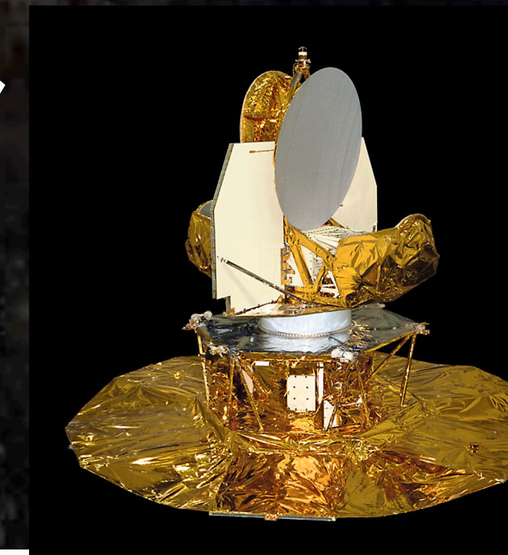
There are not enough stars to hold us inside the galaxy!

- six times more matter than all atoms combined

X

More Evidence for Dark Matter





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⇒ Weakly Interacting Massive Particle (WIMP)

X

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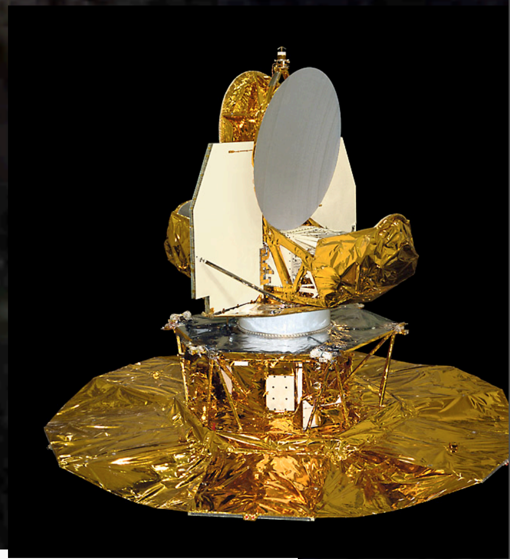

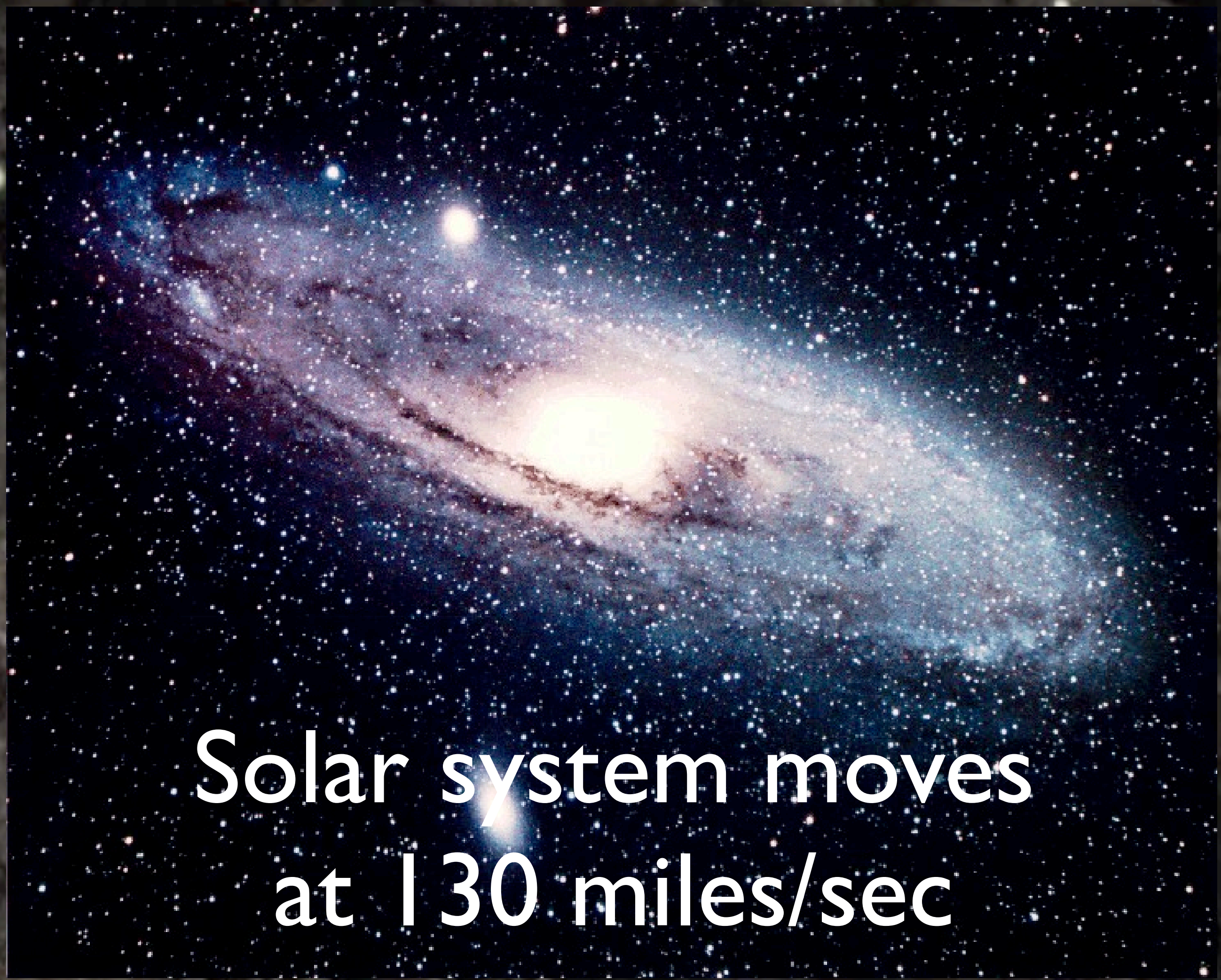

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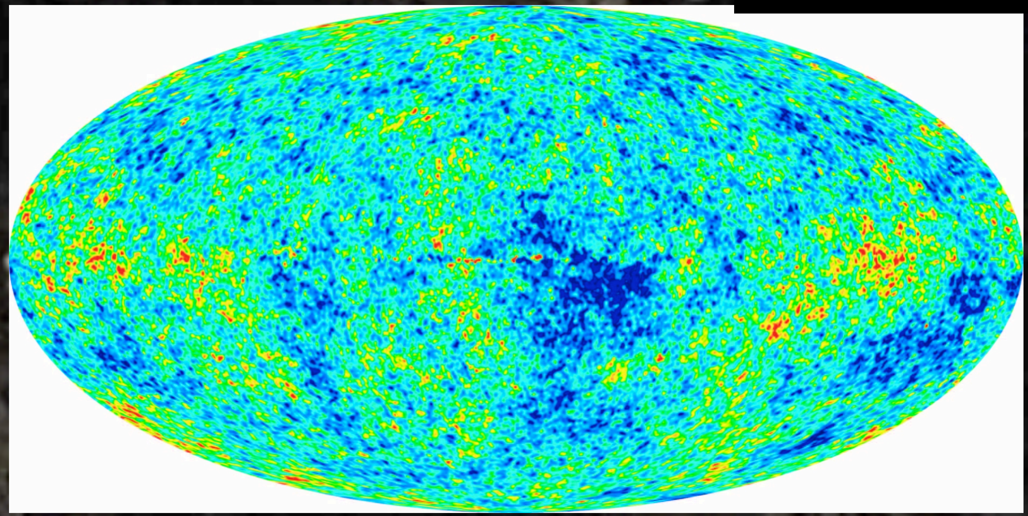

- six times more matter than all atoms combined

$\Rightarrow$ Weakly Interacting Massive Particle (WIMP)

- Leftovers from the Big Bang

X

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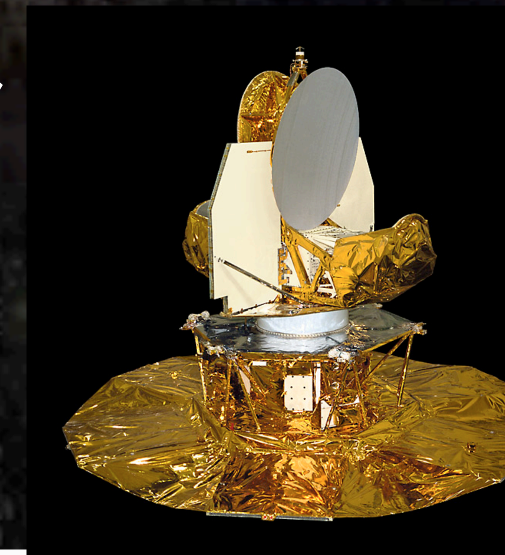

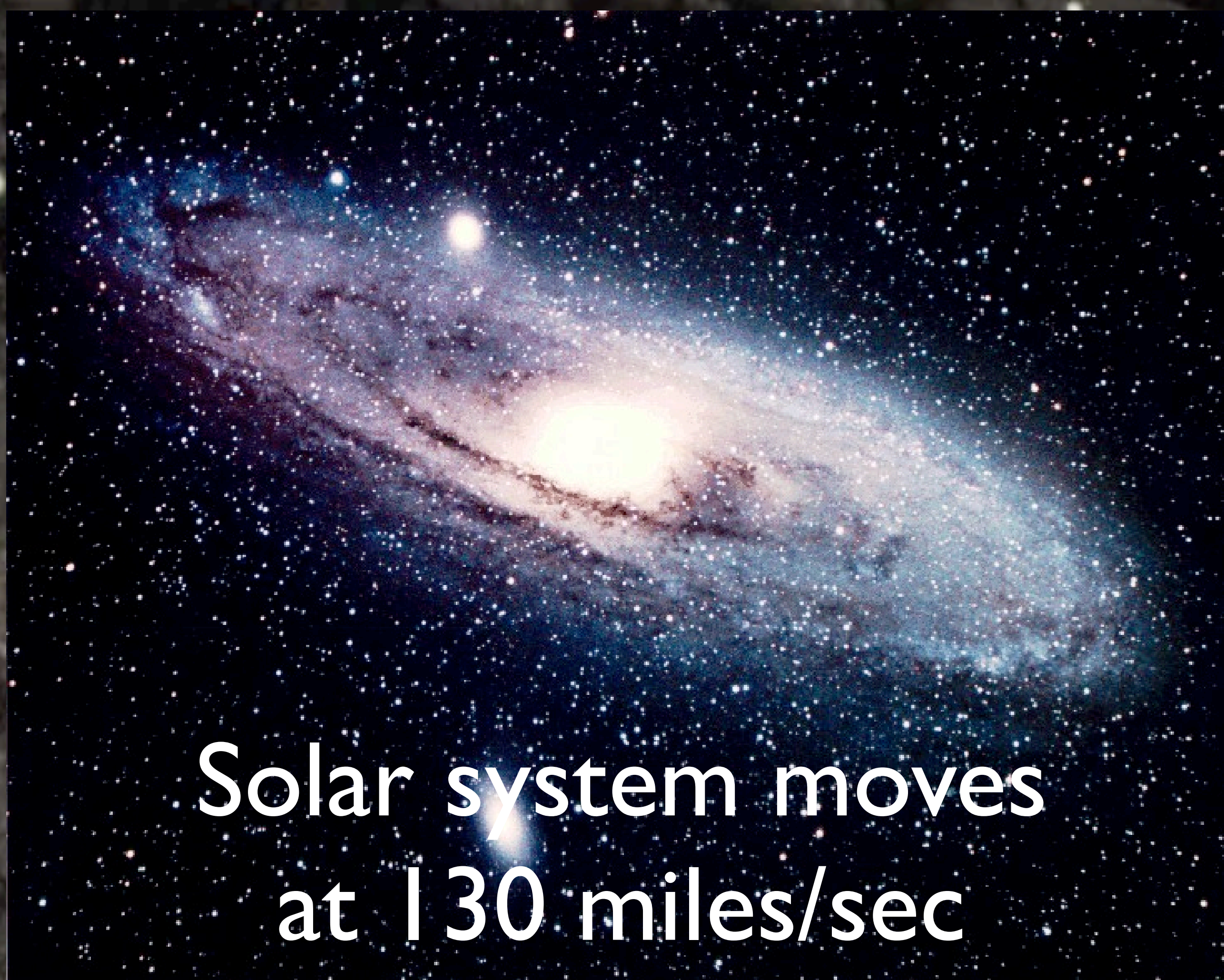

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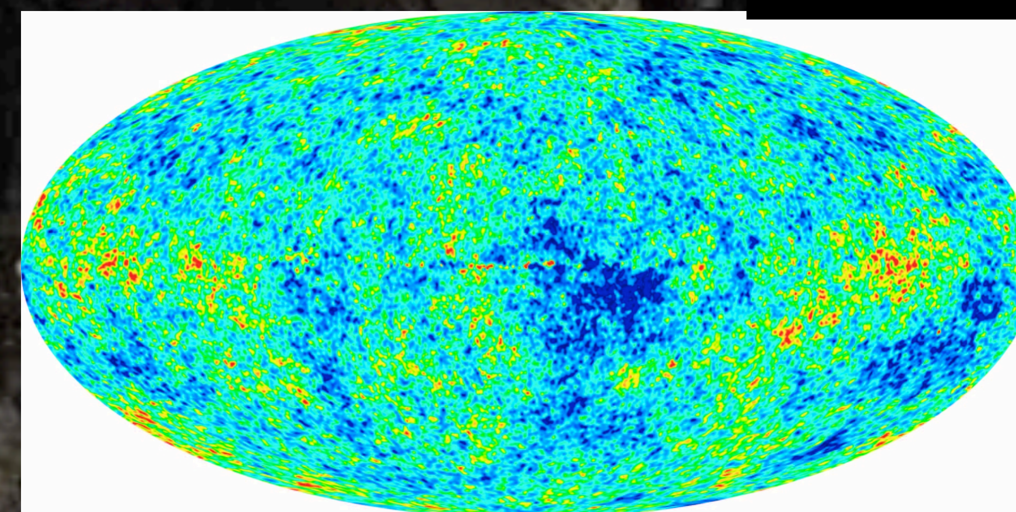


- six times more matter than all atoms combined

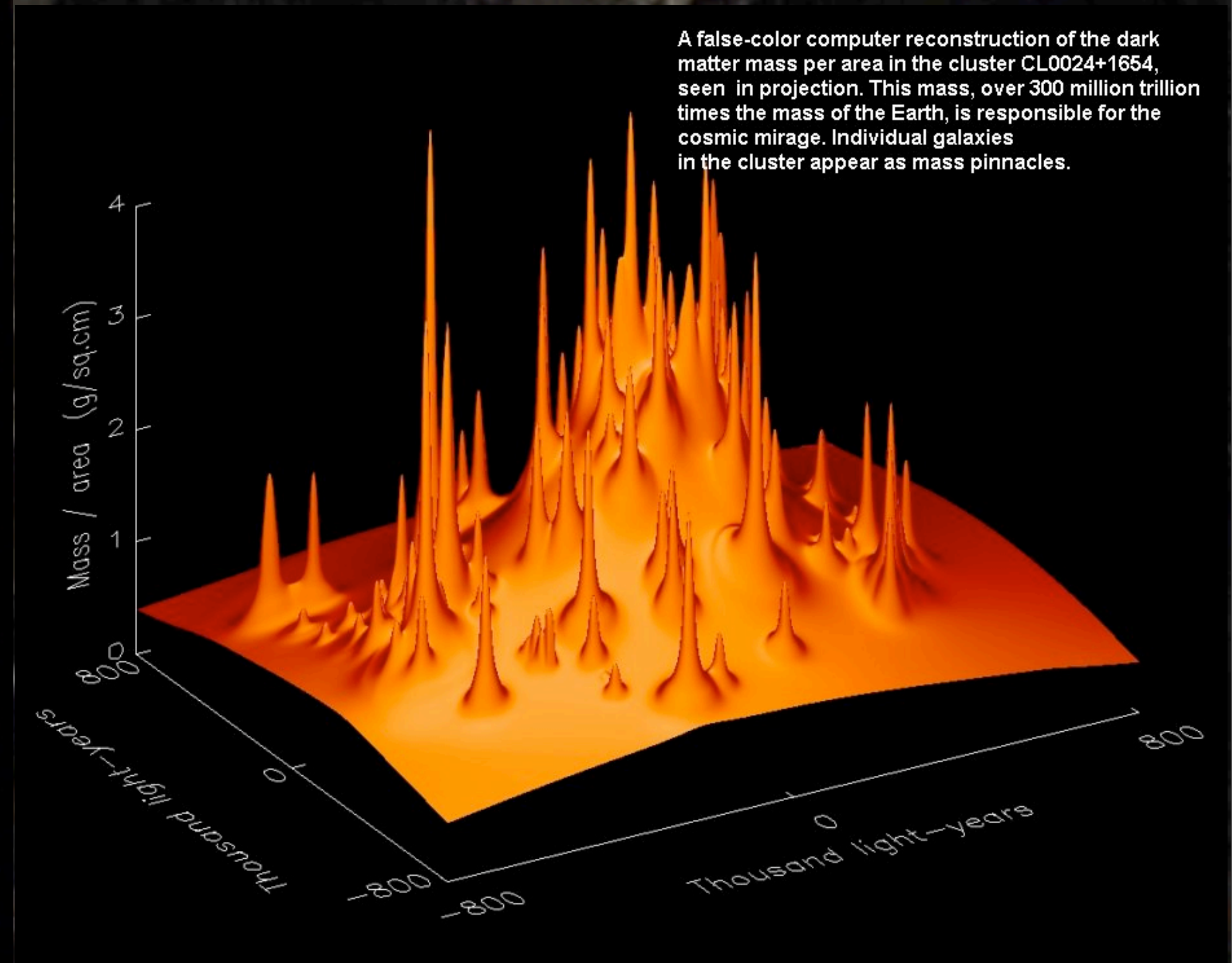
⇒ Weakly Interacting Massive Particle (WIMP)

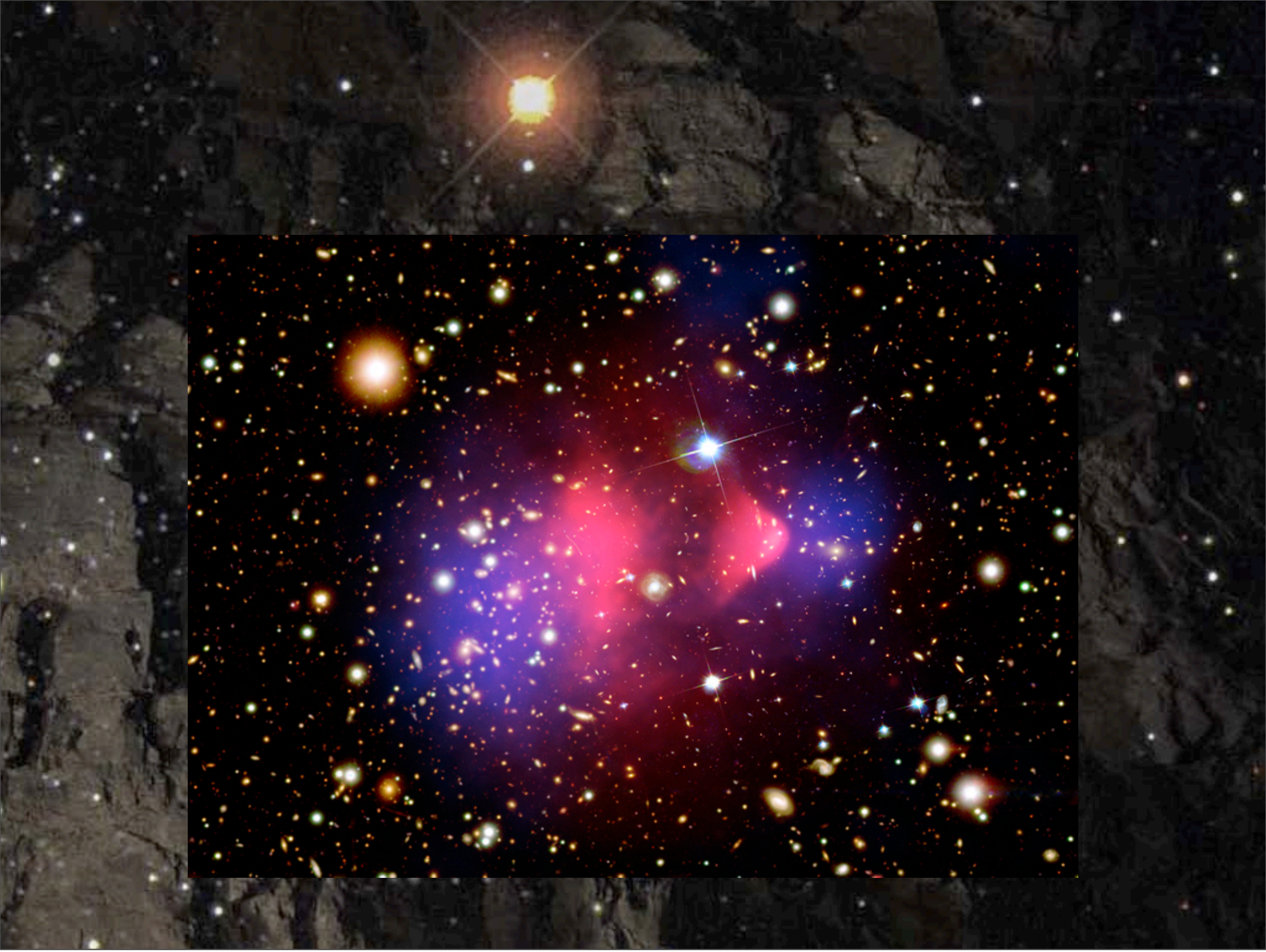
- Leftovers from the Big Bang

Invisible!

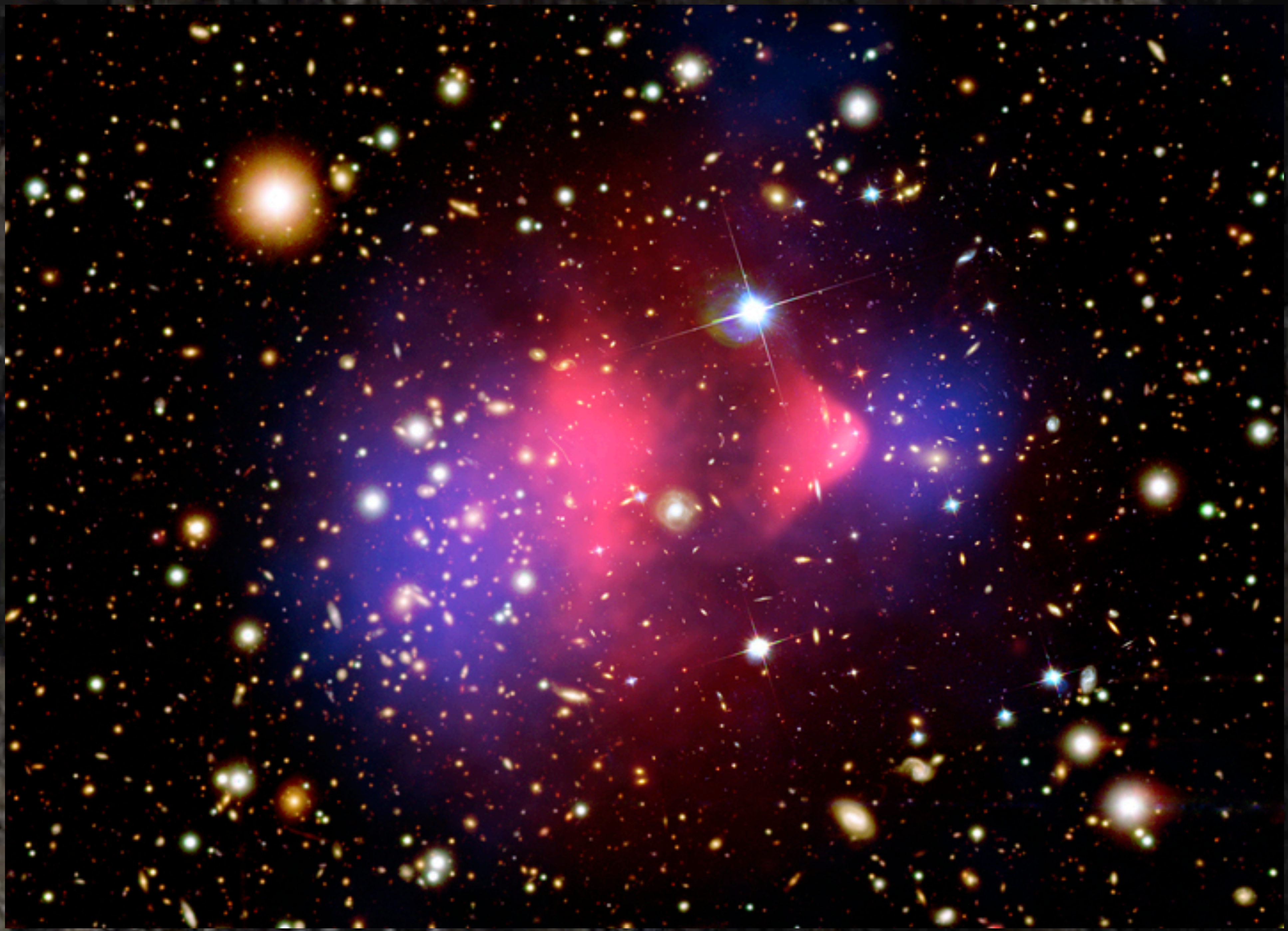
X

Cluster of galaxies





You don’t want to be there



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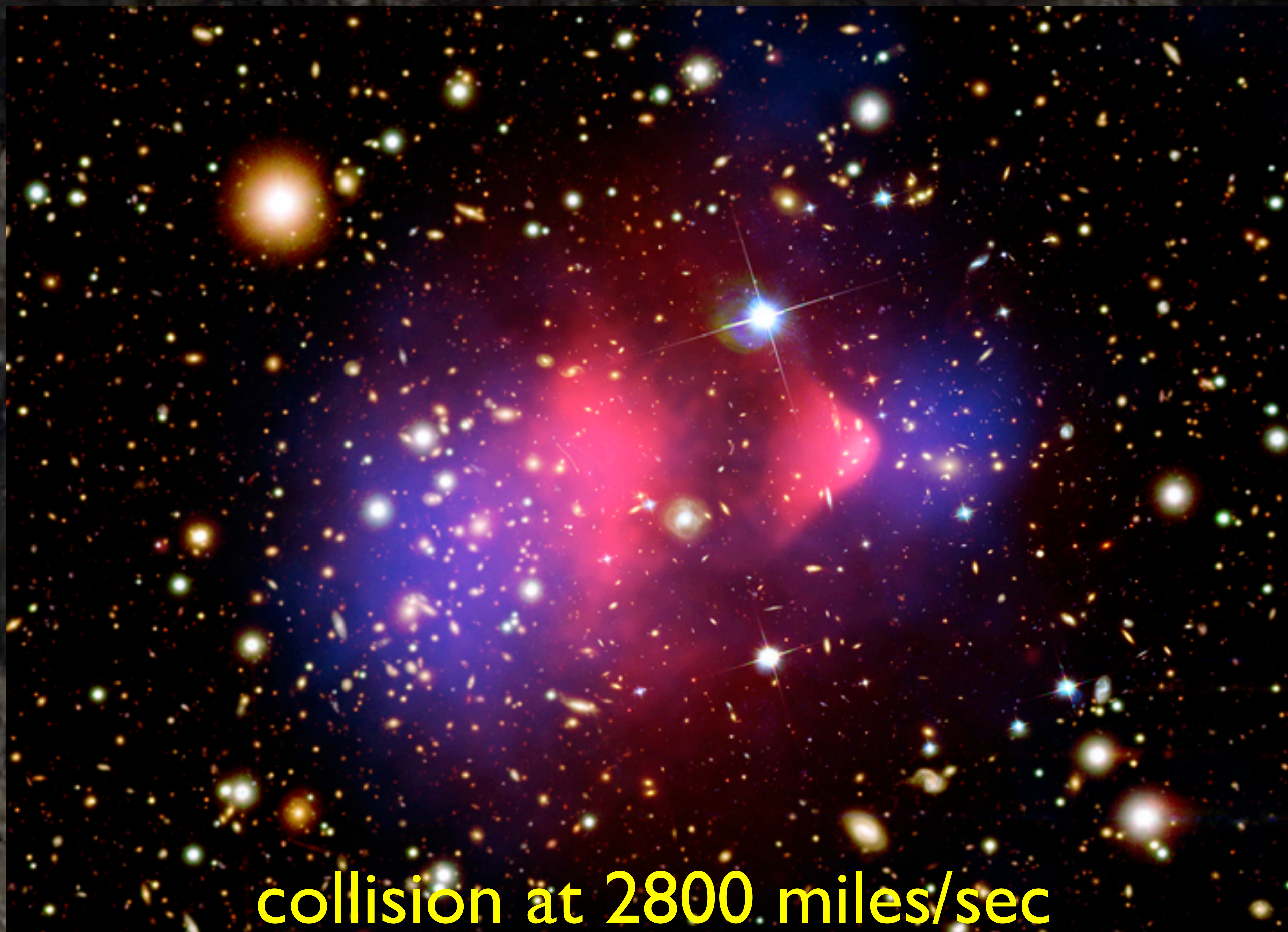

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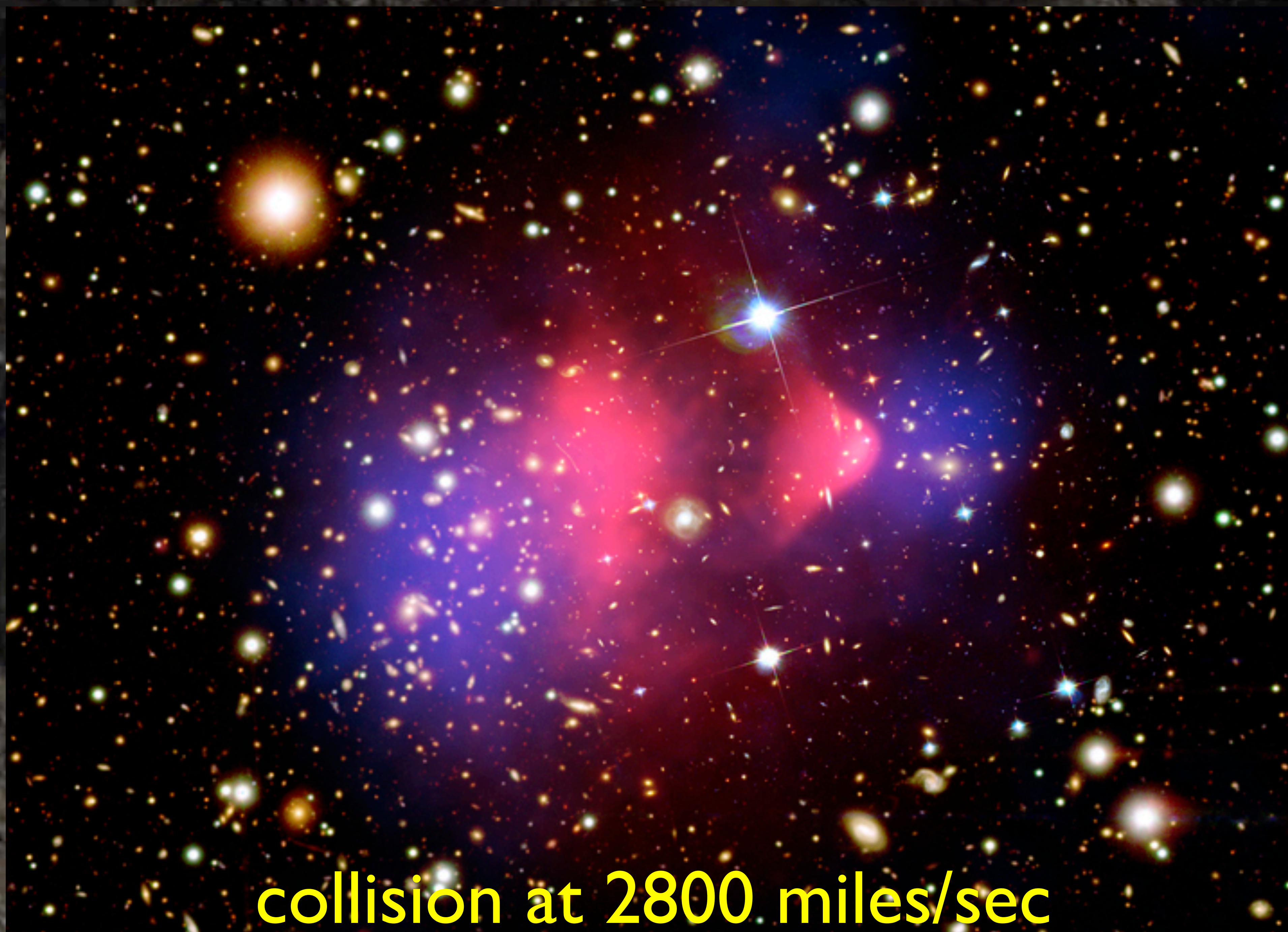
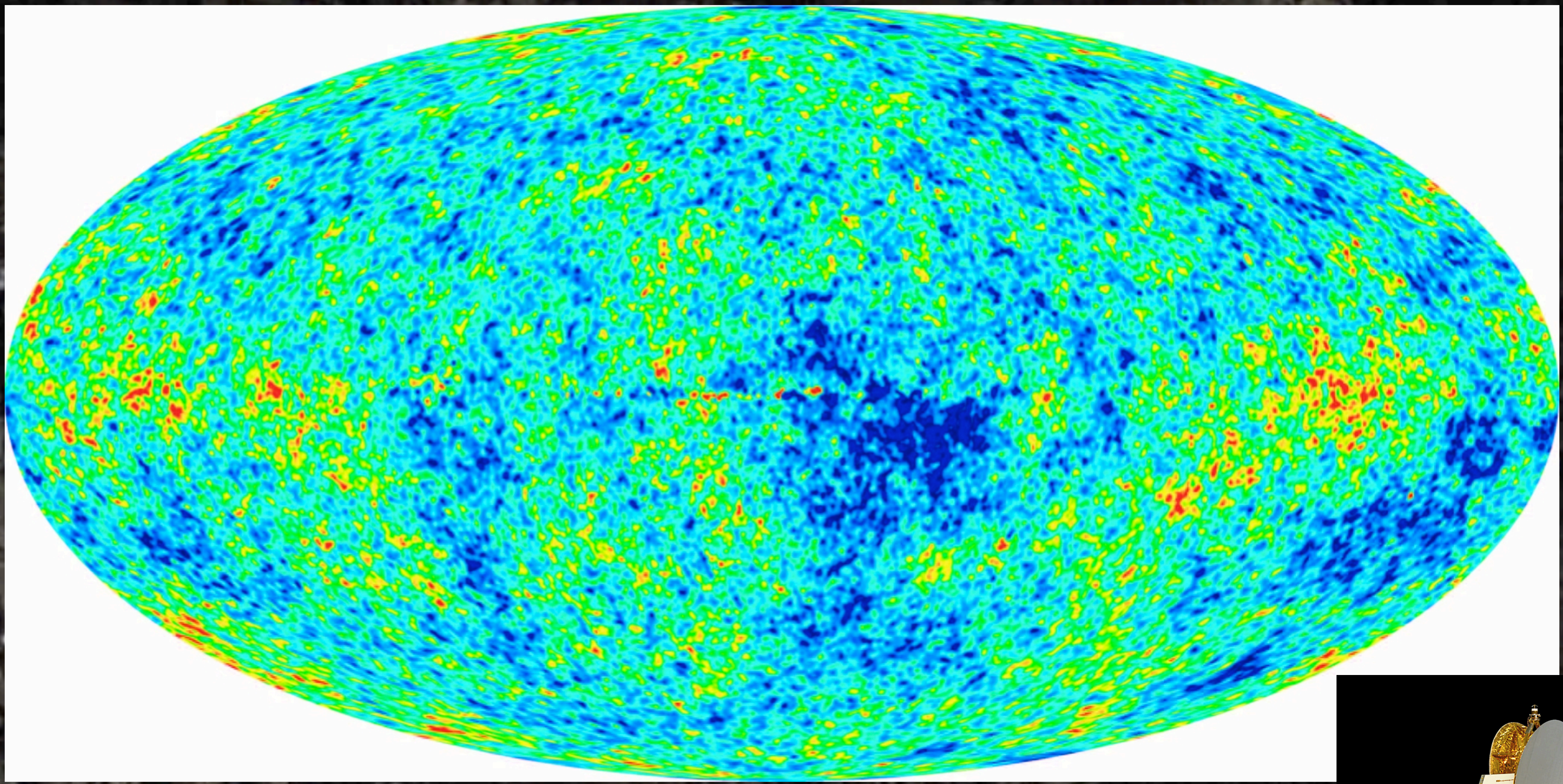


Whole Universe



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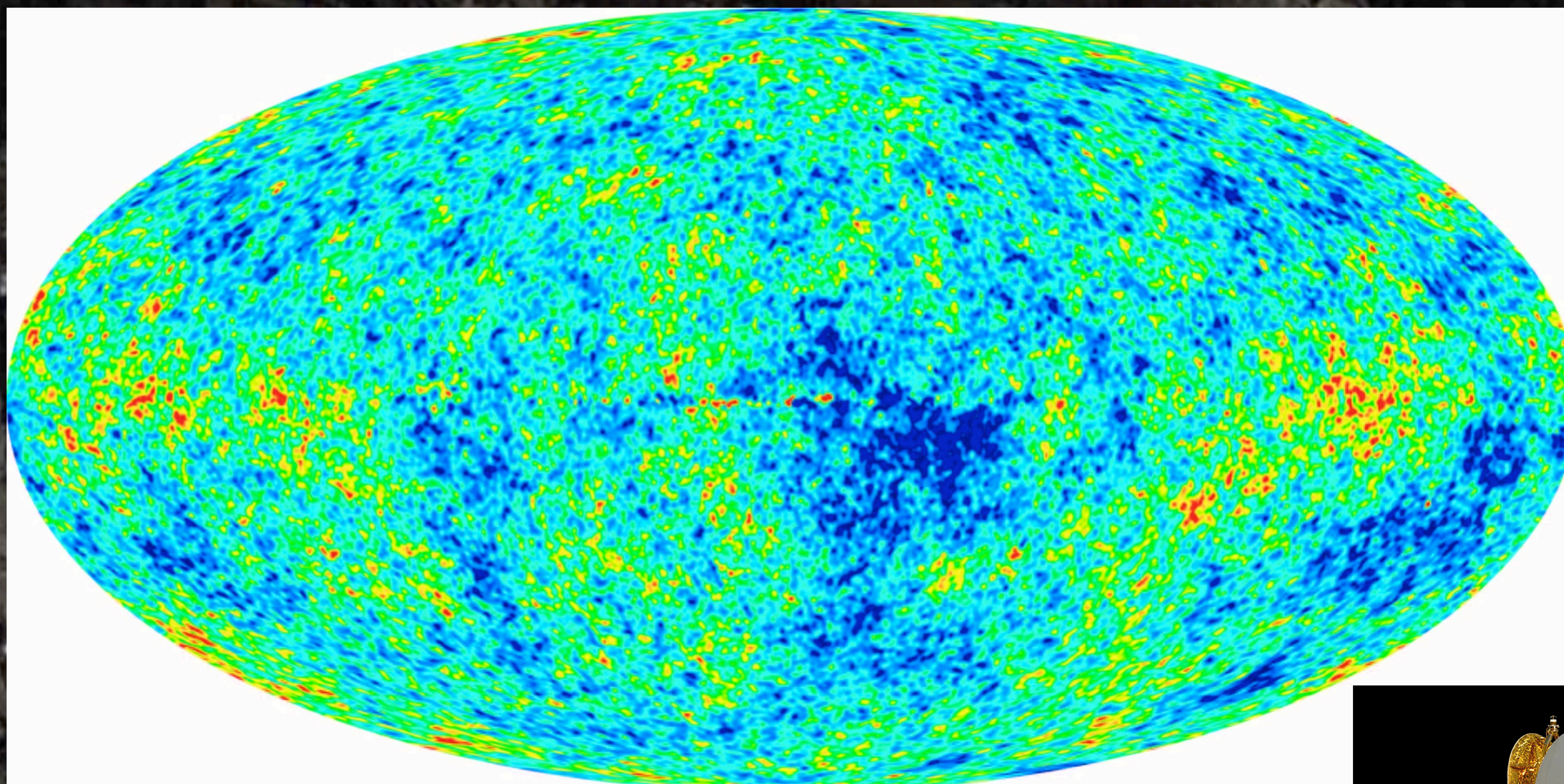
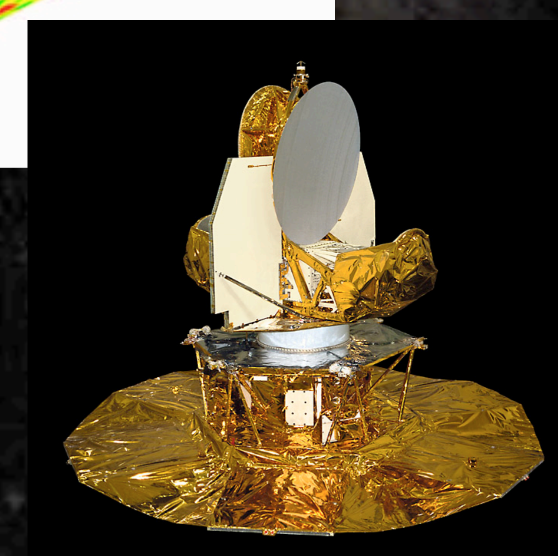
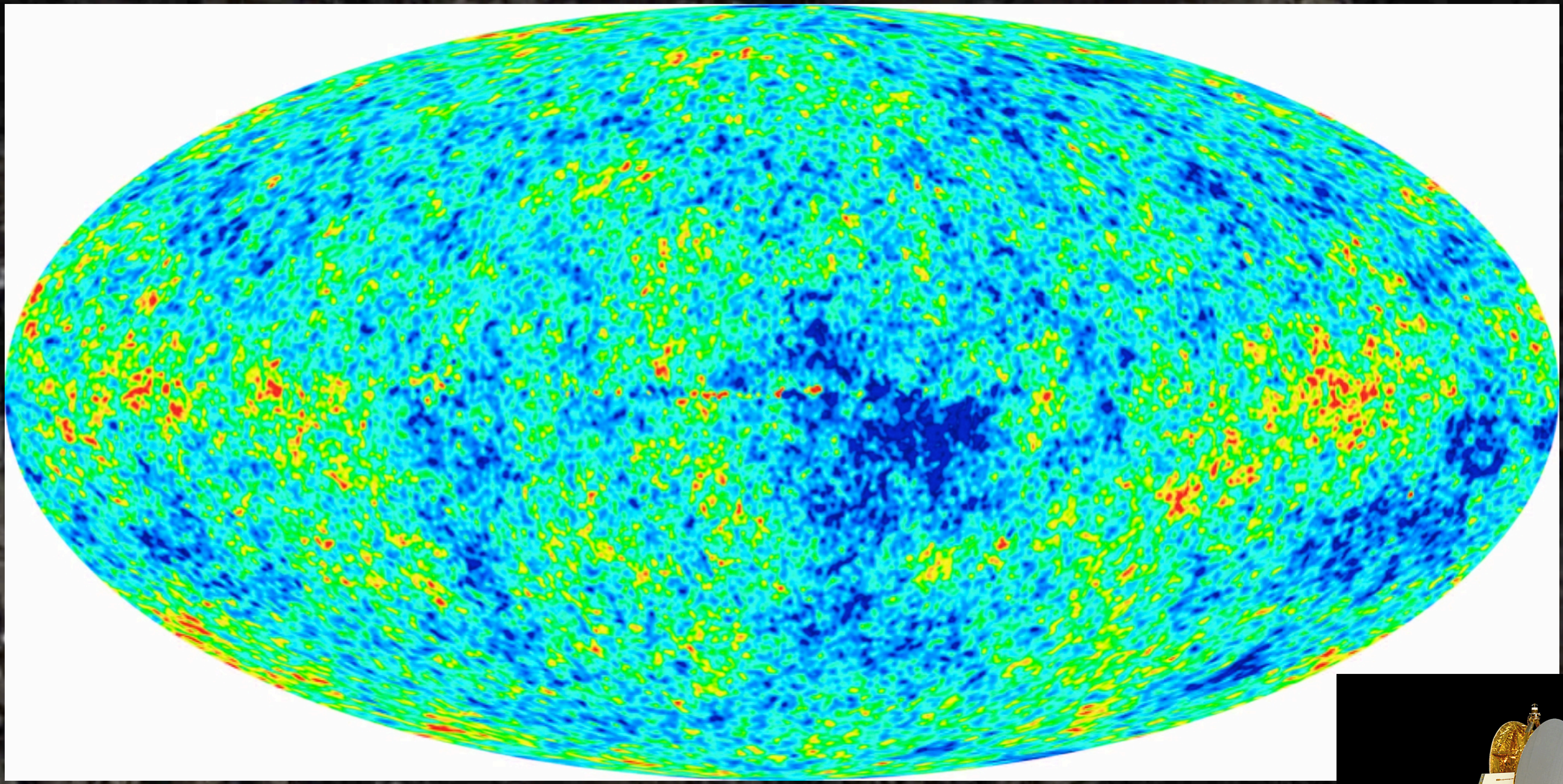




- matter=all atomsx6

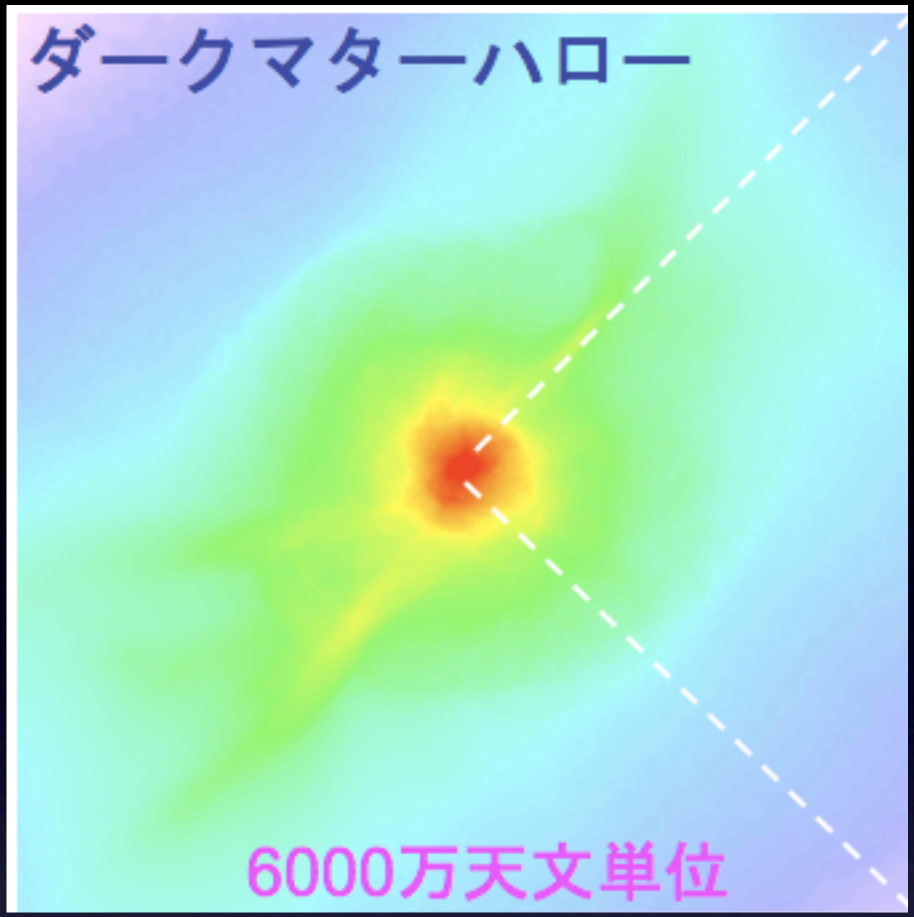
Whole Universe



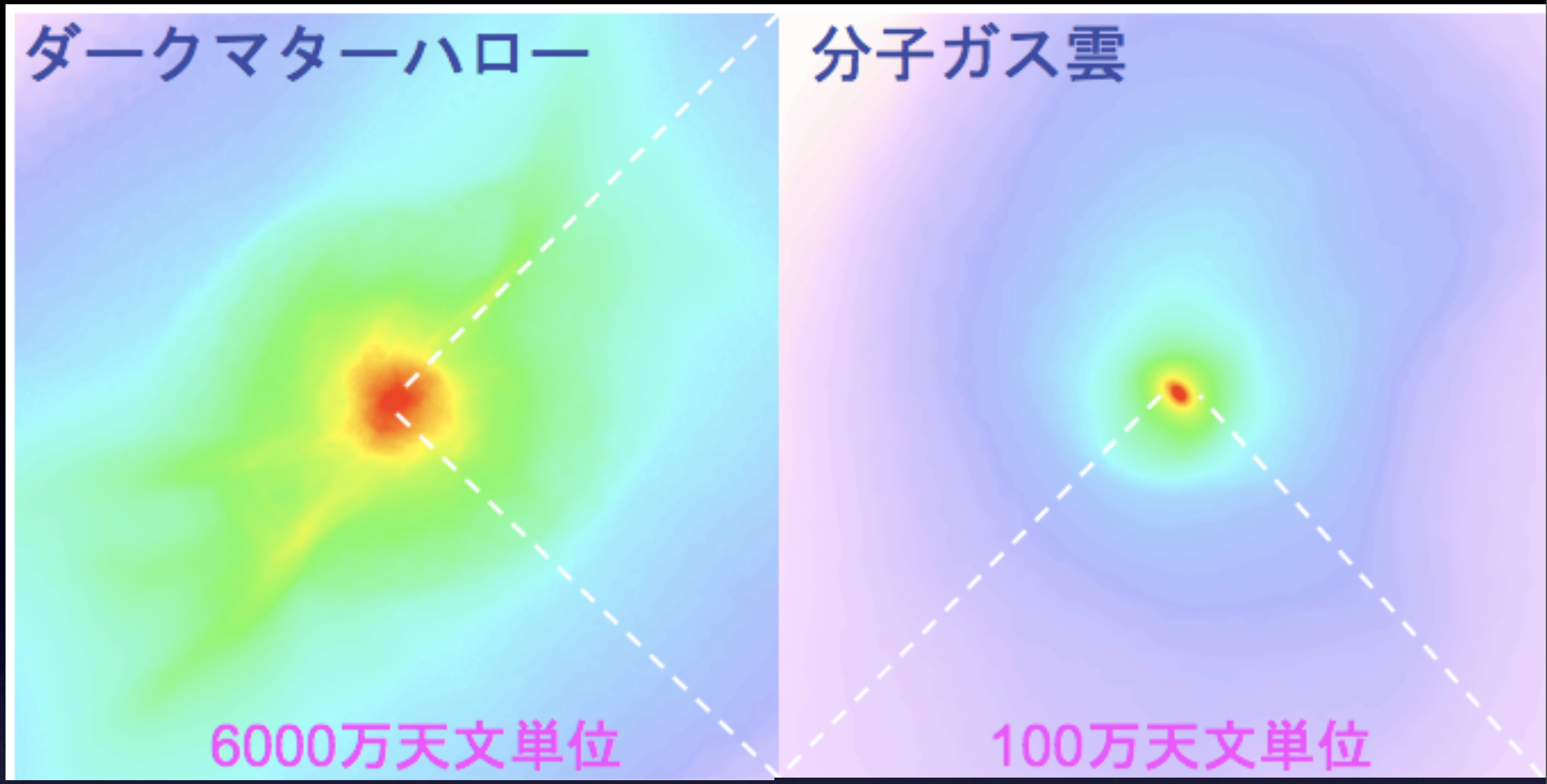
- matter=all atomsx6
- invisible & unknown matter dominates the universe!


We don't exist
without dark matter
Without Dark Matter
With Dark Matter

Birth of First Star



Birth of First Star



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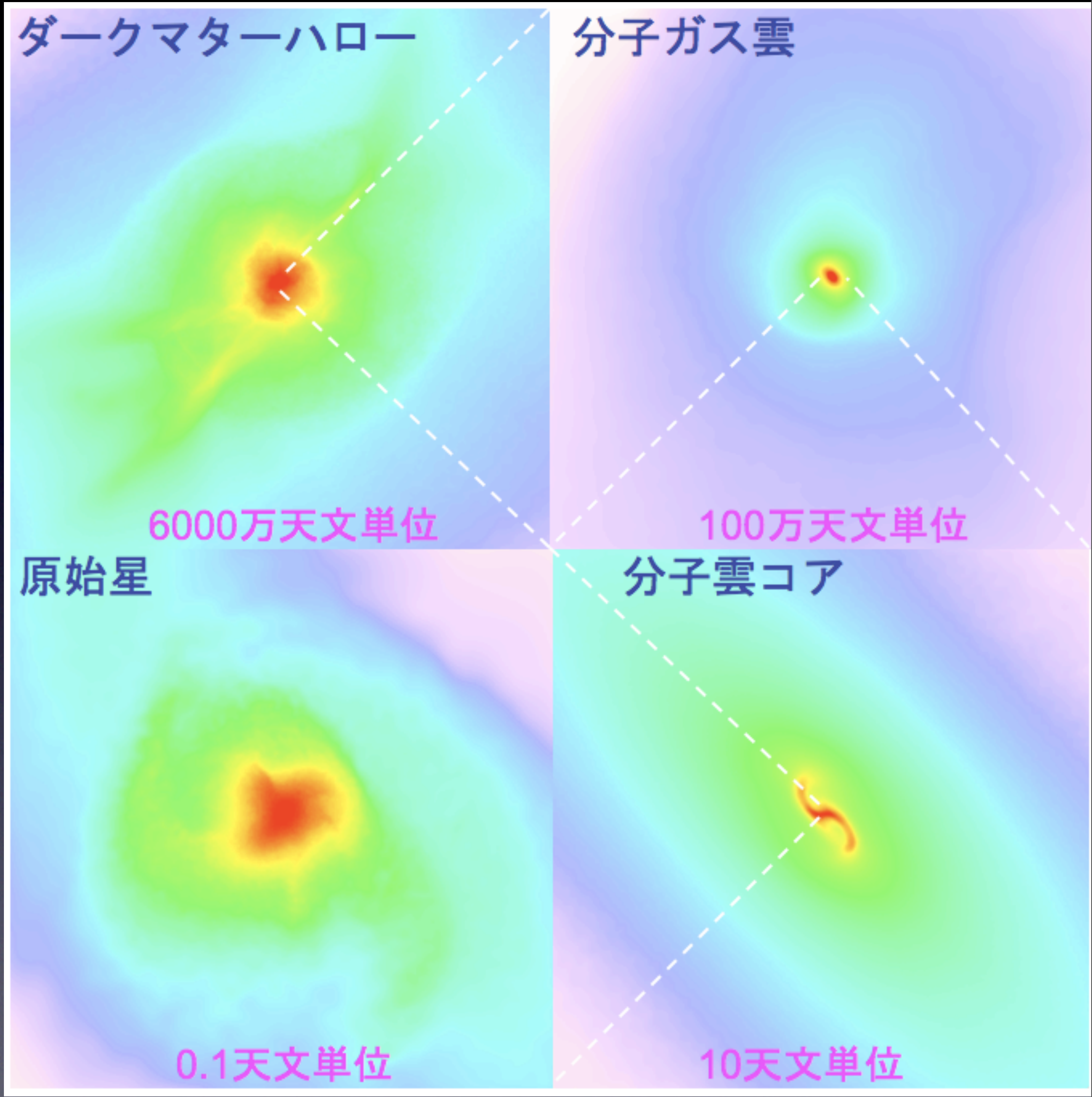
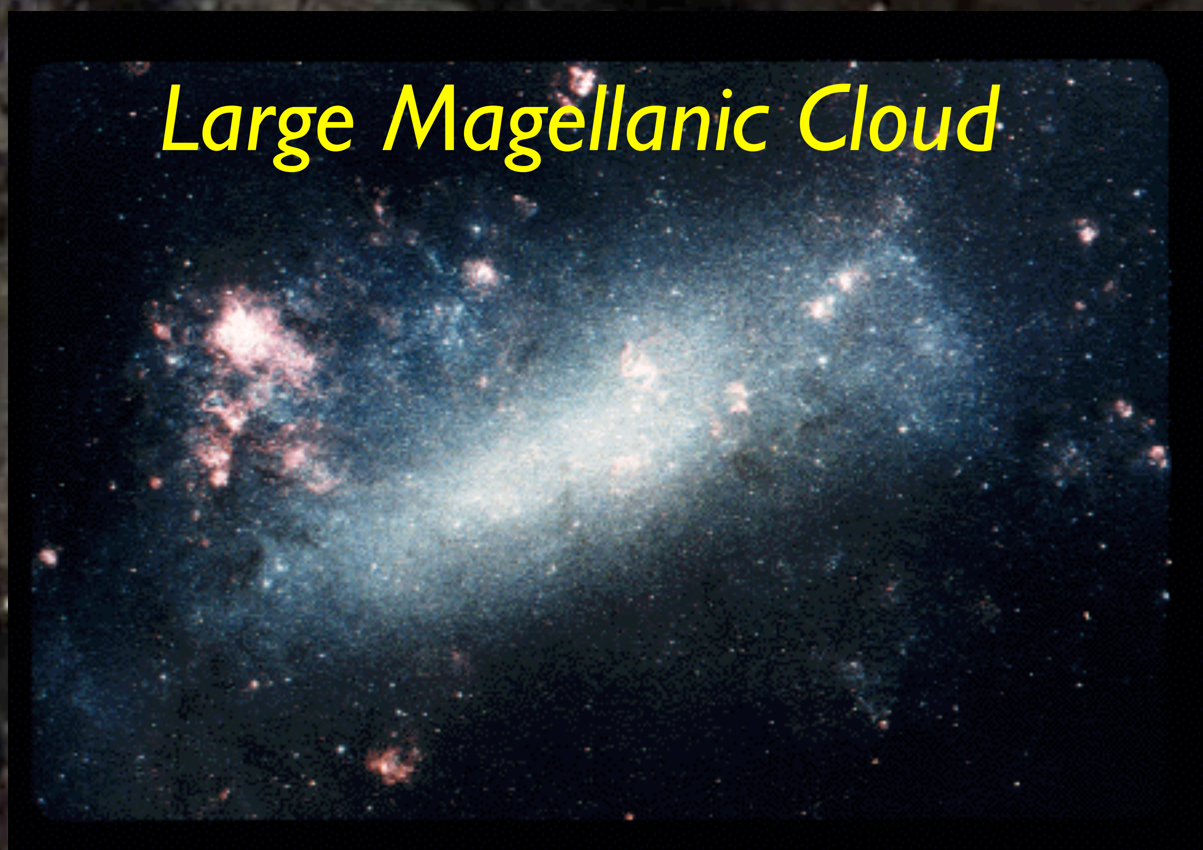


Dim Stars?

Search for MACHOs
(Massive Compact Halo Objects)



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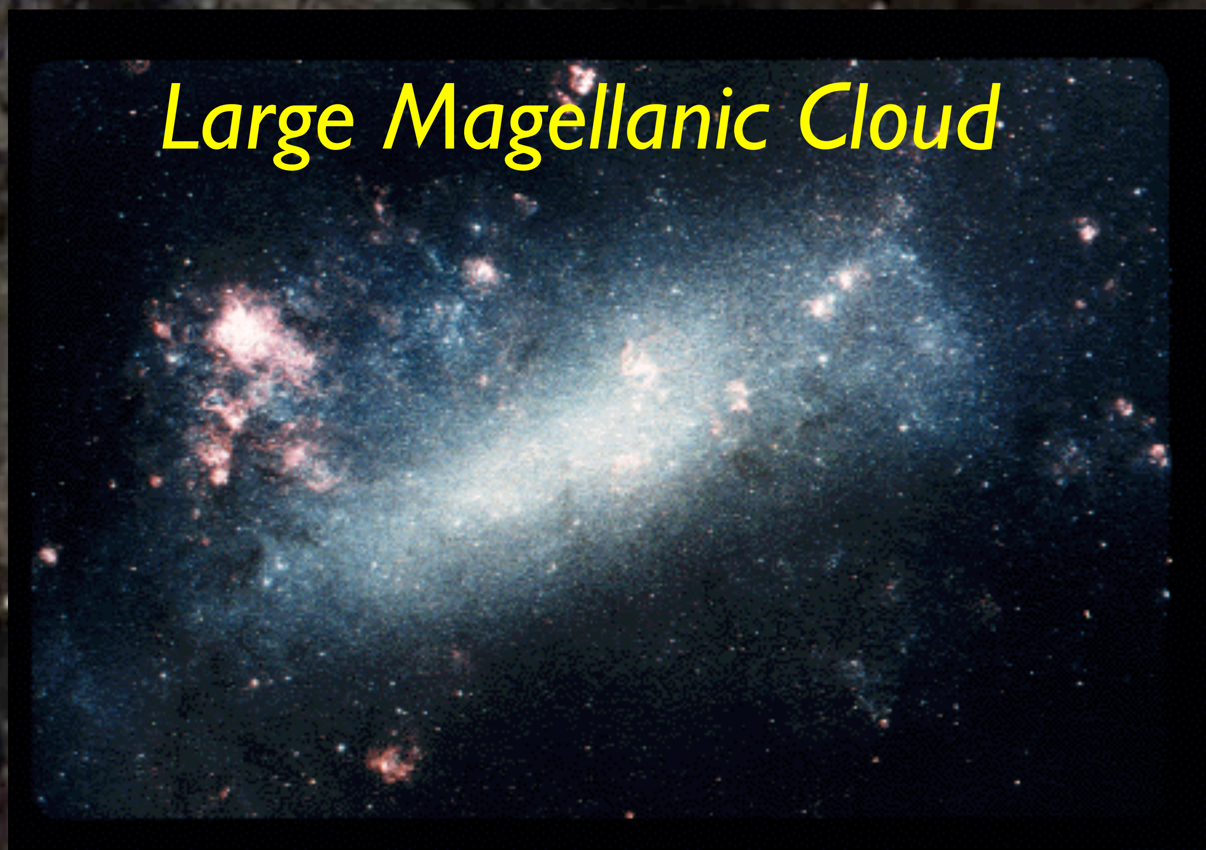

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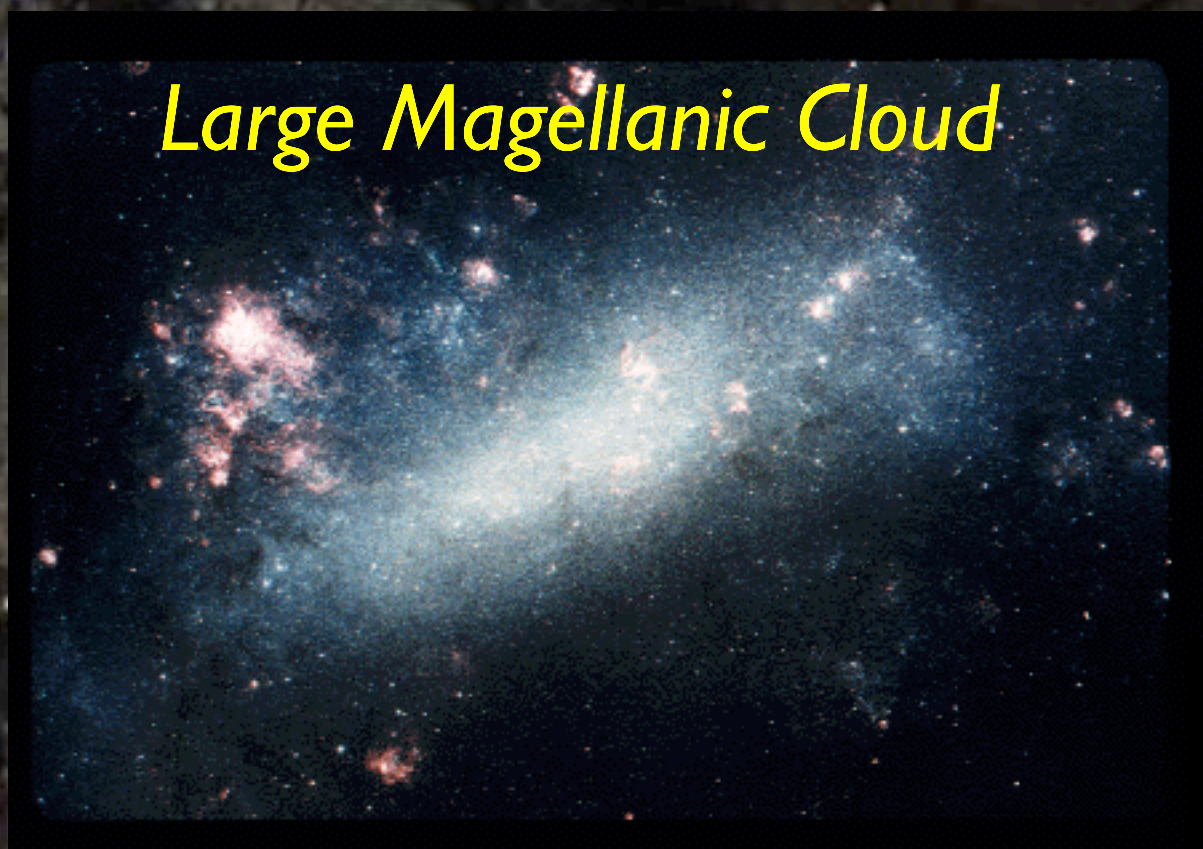

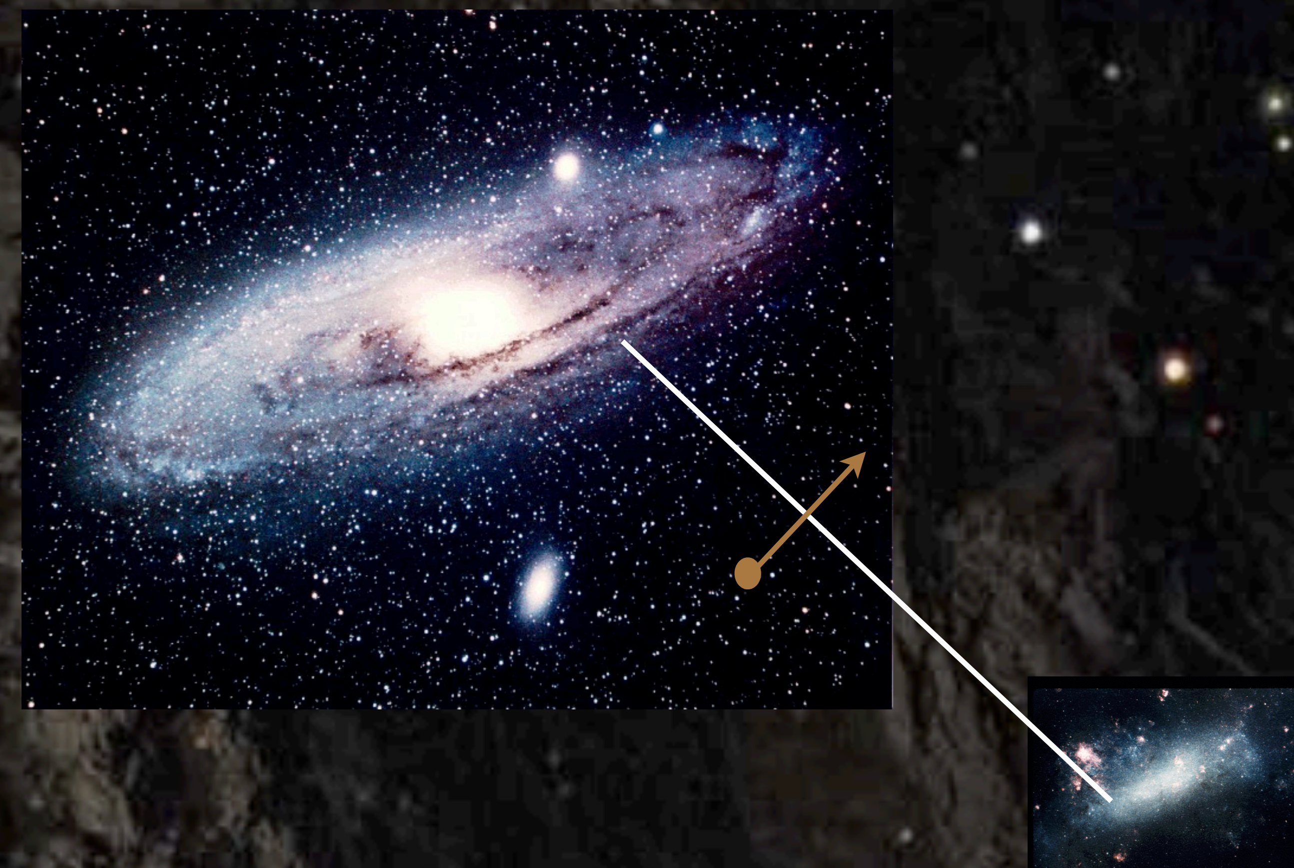

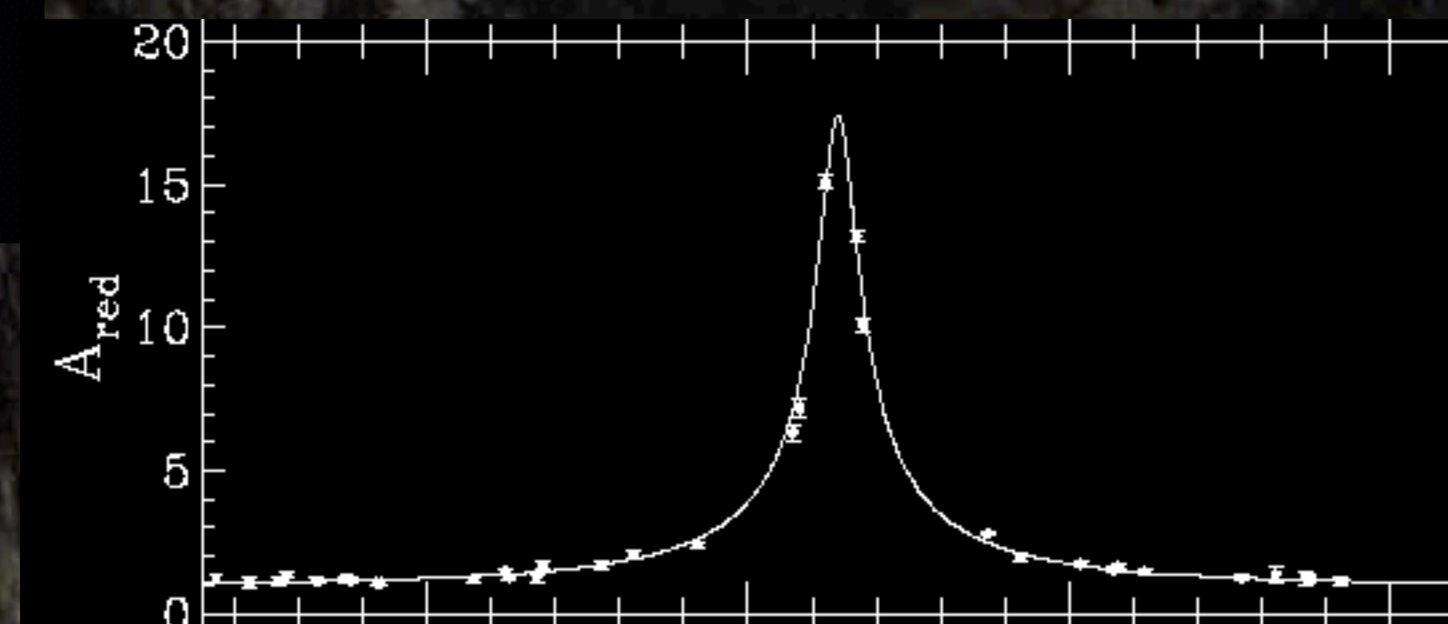

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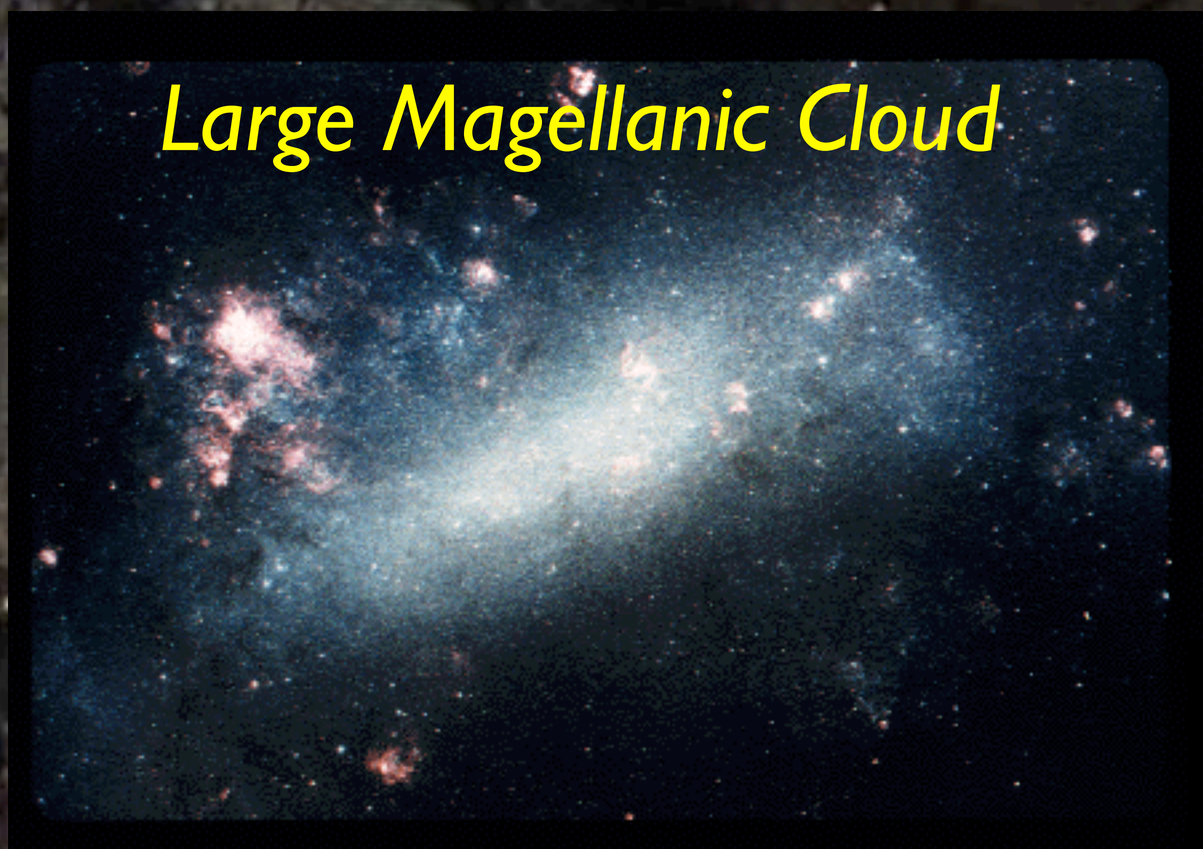

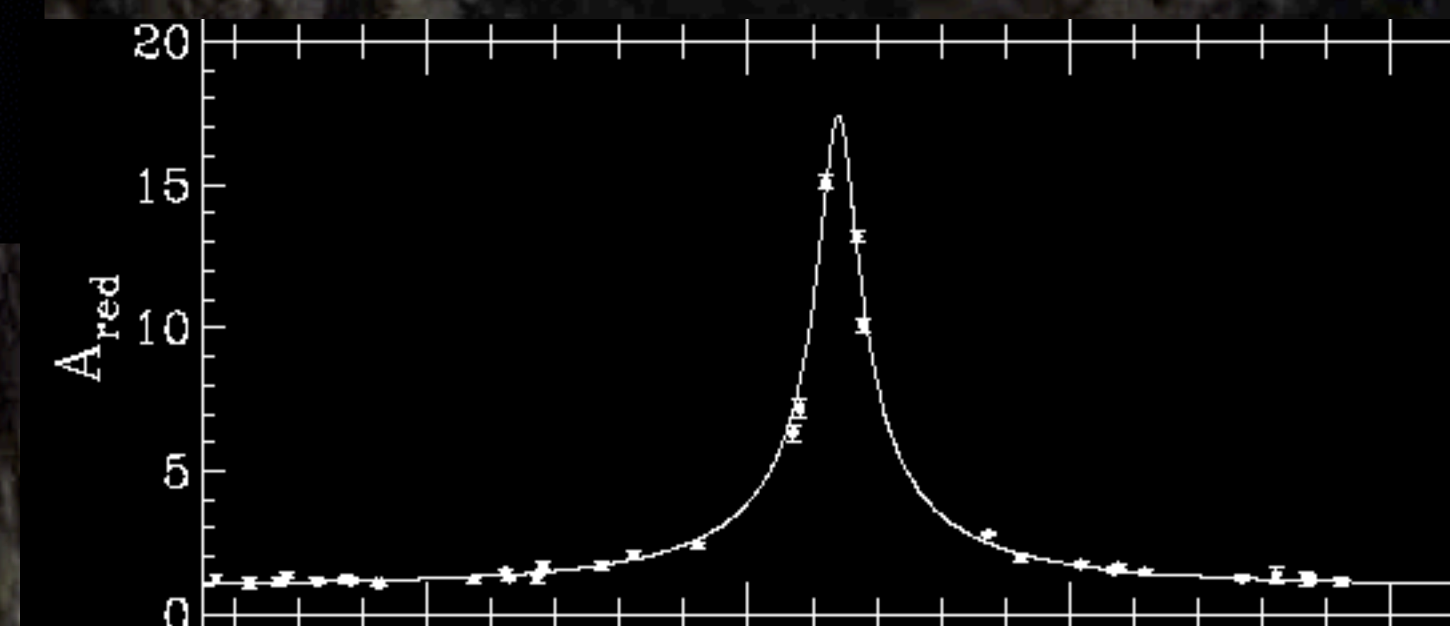

Not enough of them!

Dim Stars?

Search for MACHOs
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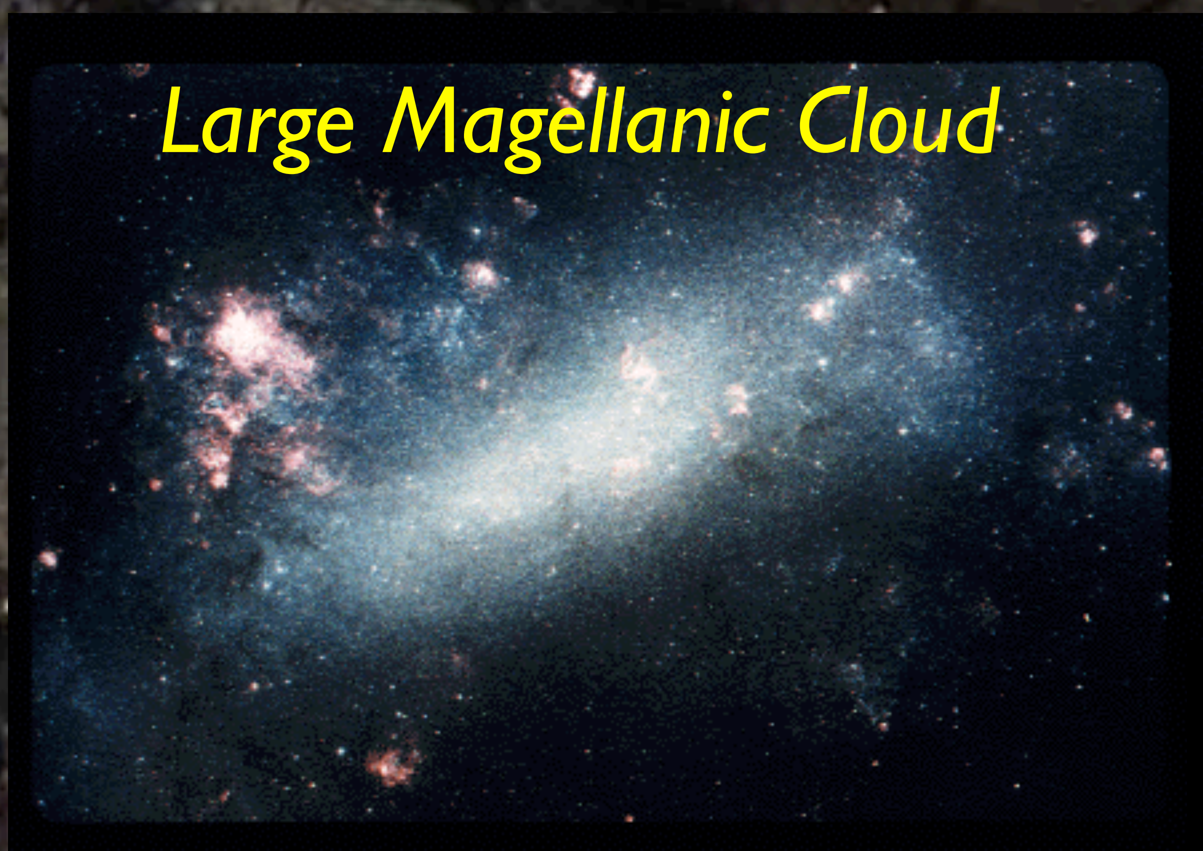
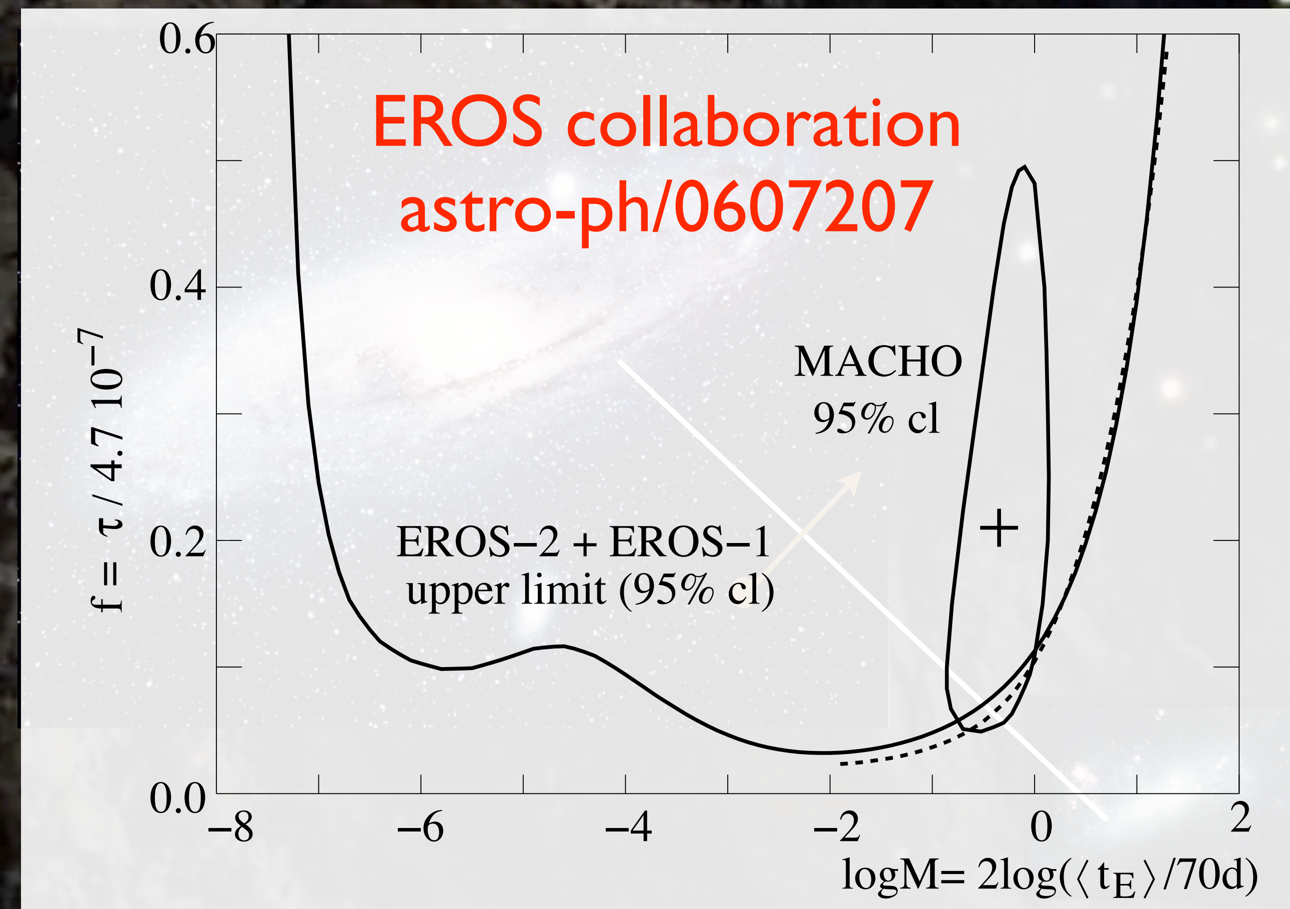
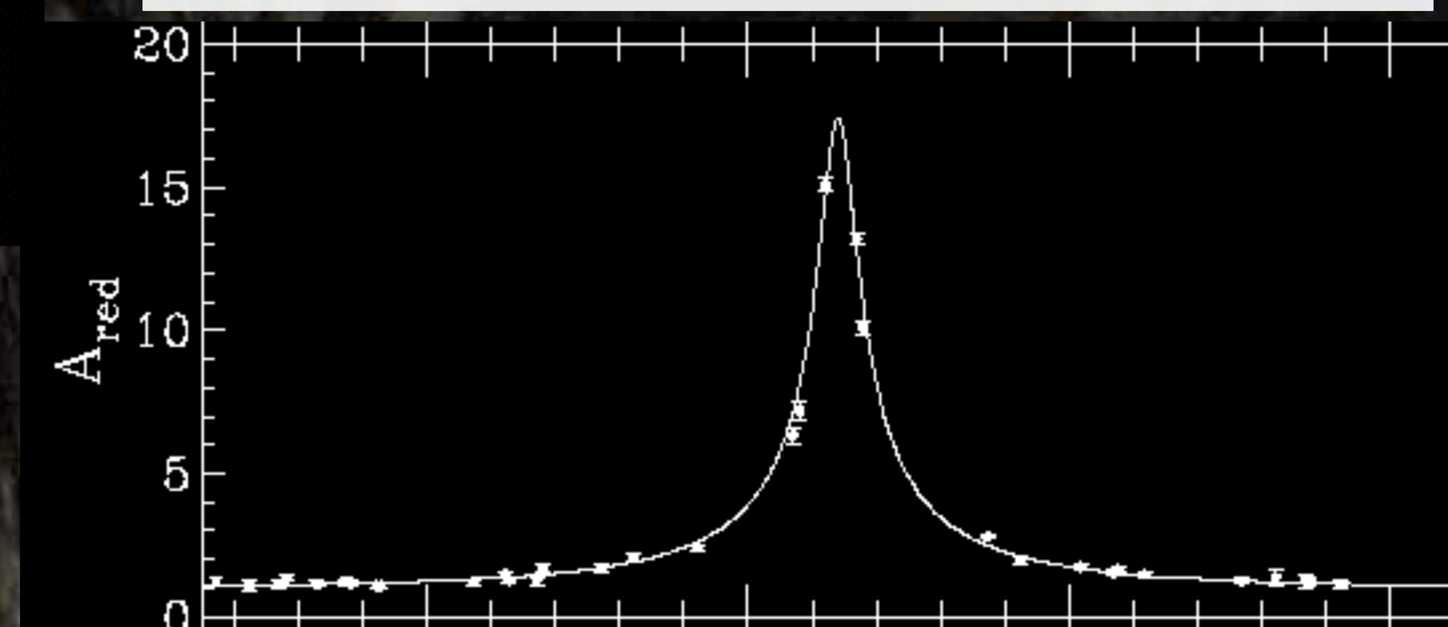
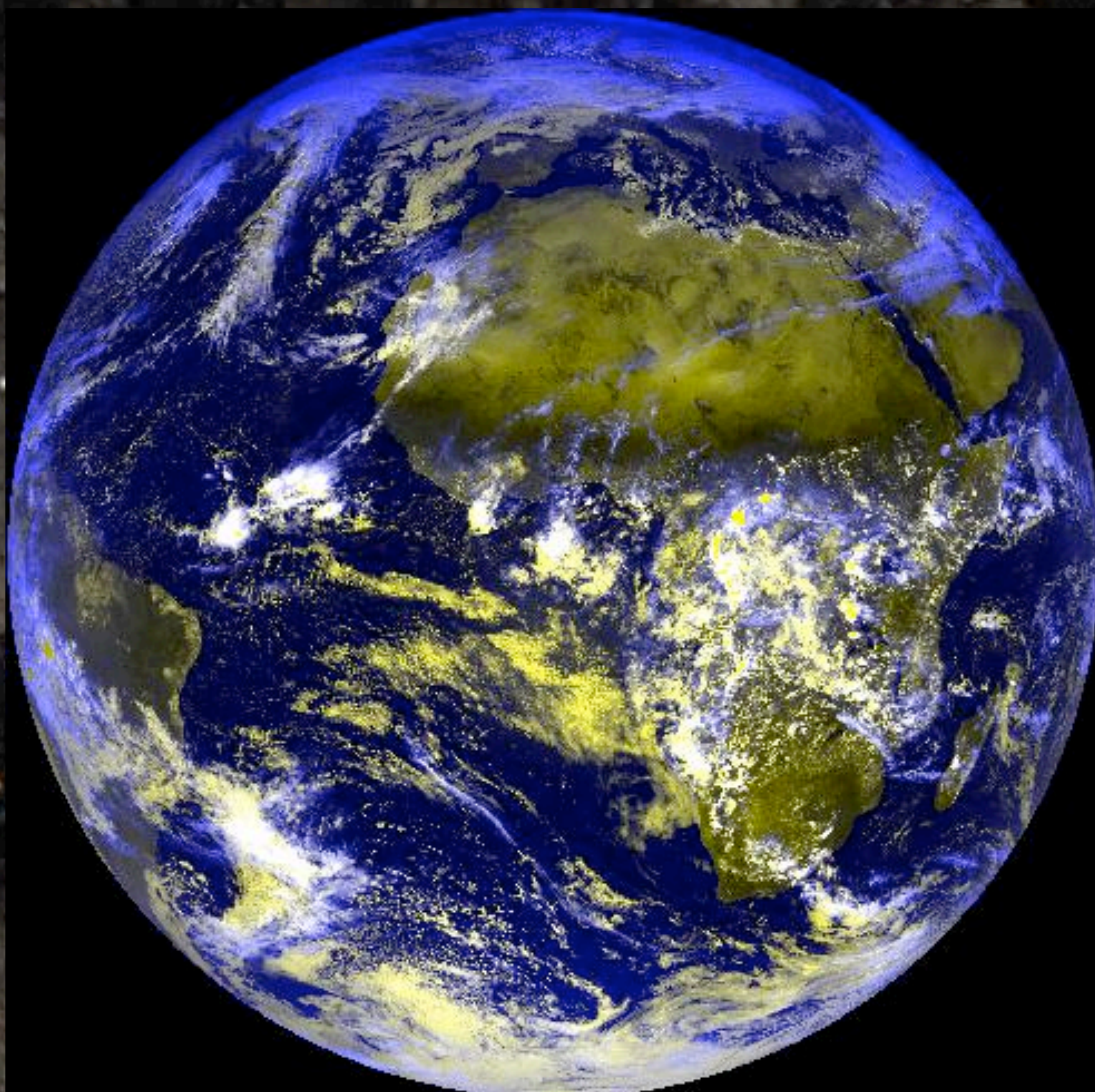






Not enough of them!

MACHO $\Rightarrow$ WIMP



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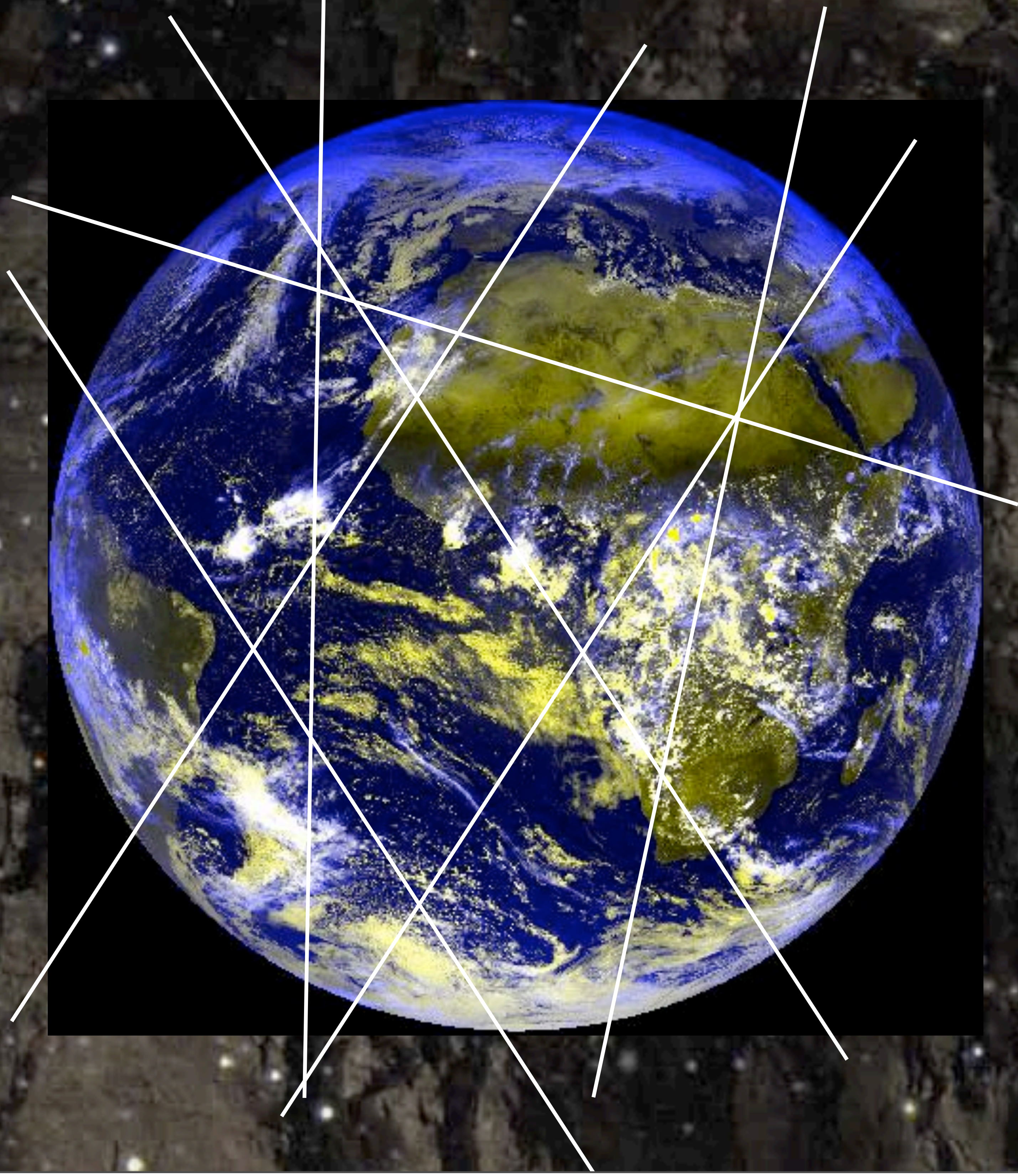
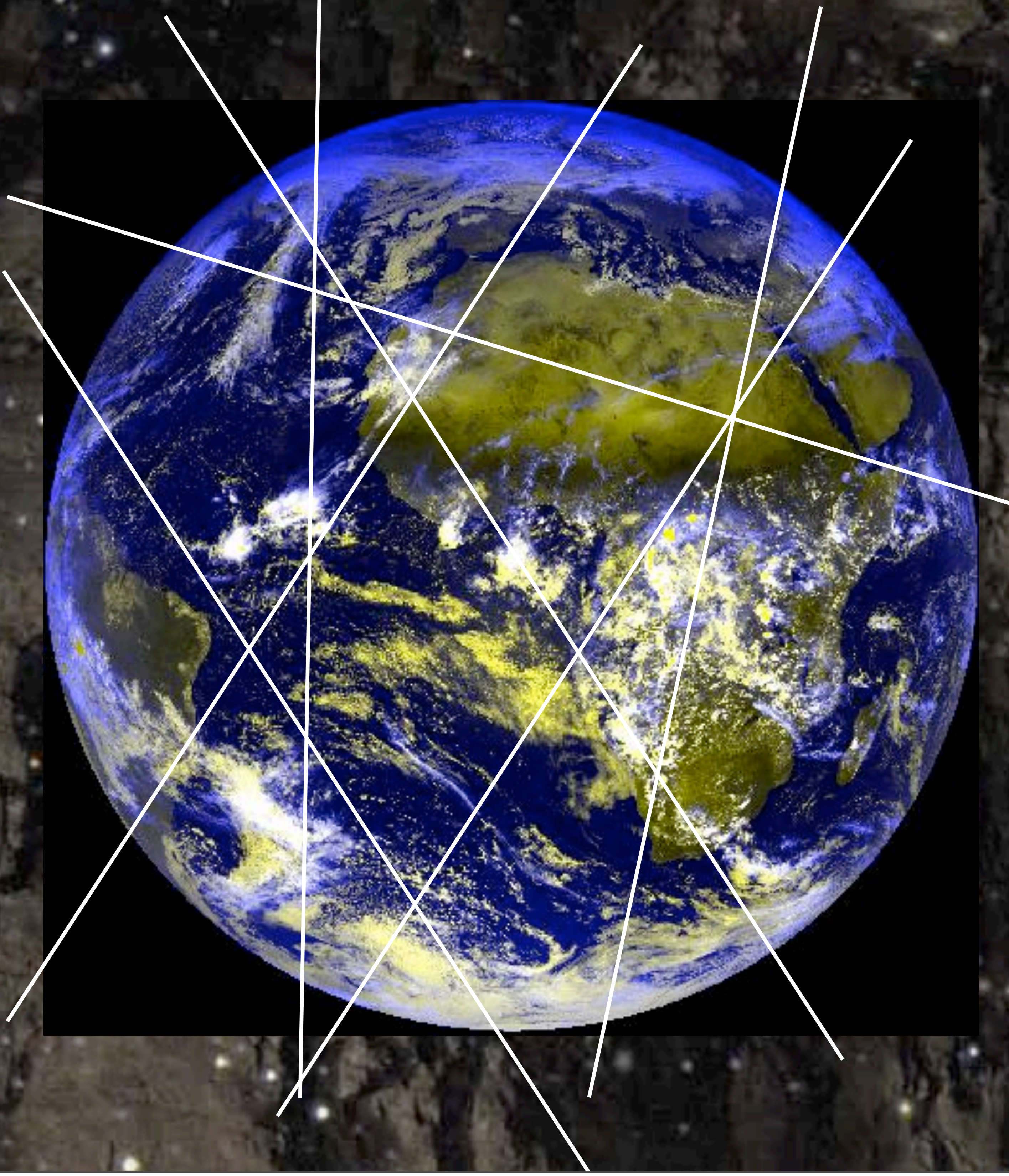
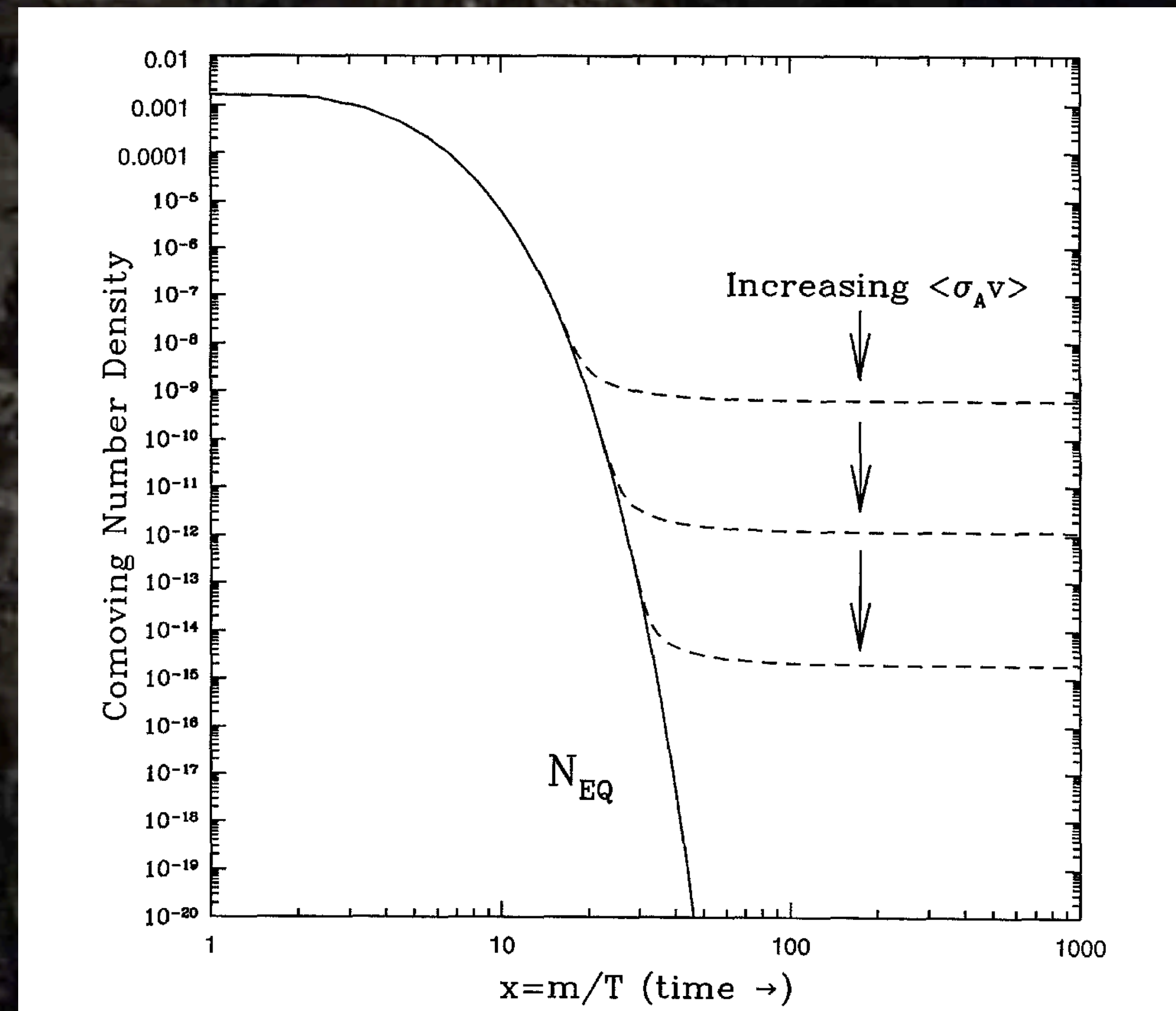


MACHO ⇒ WIMP



- *It must be WIMP (Weakly Interacting Massive Particle)*
- *Stable heavy particle produced in early Universe, left-over from near-complete annihilation*

thermal relic



thermal relic

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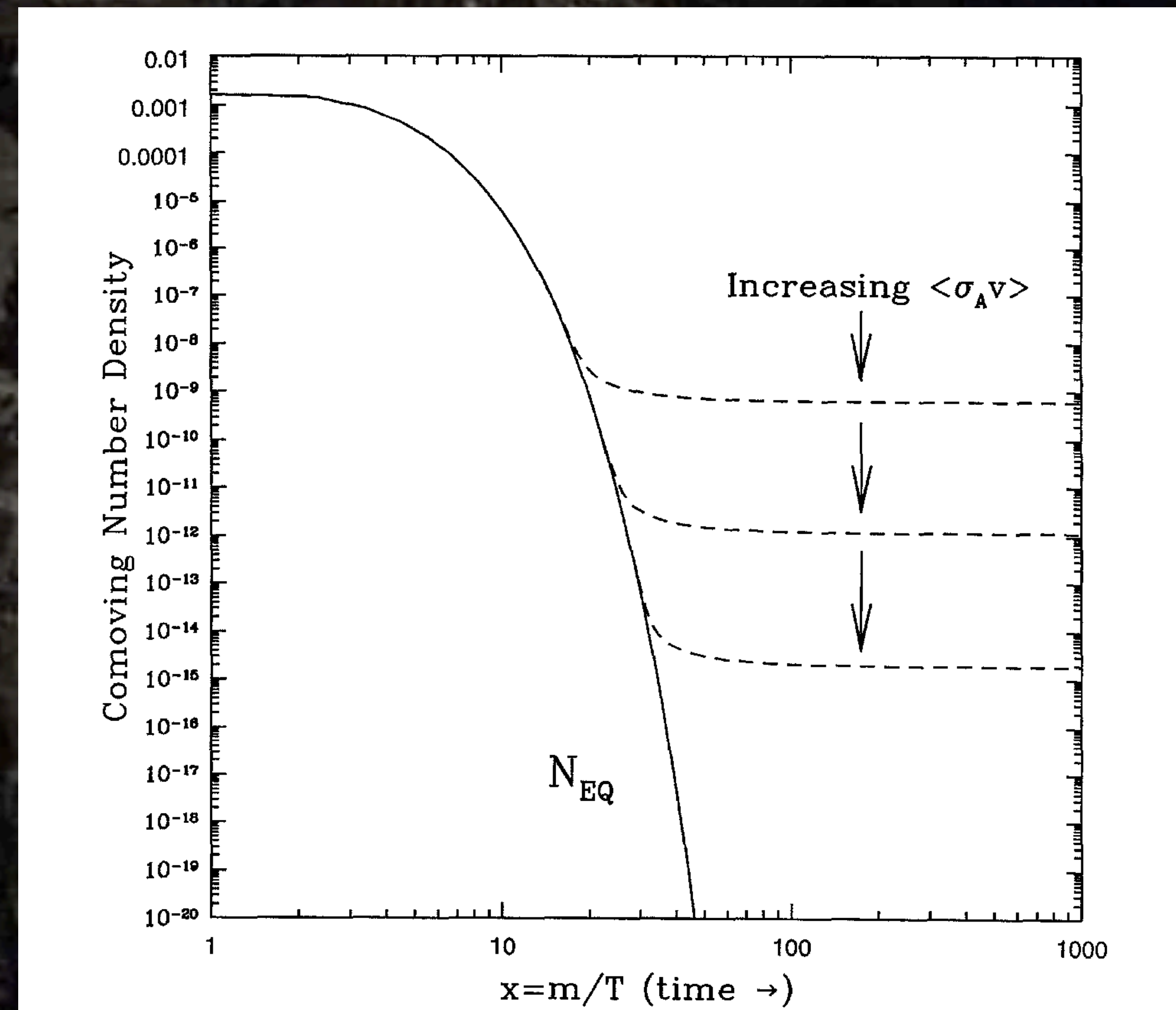

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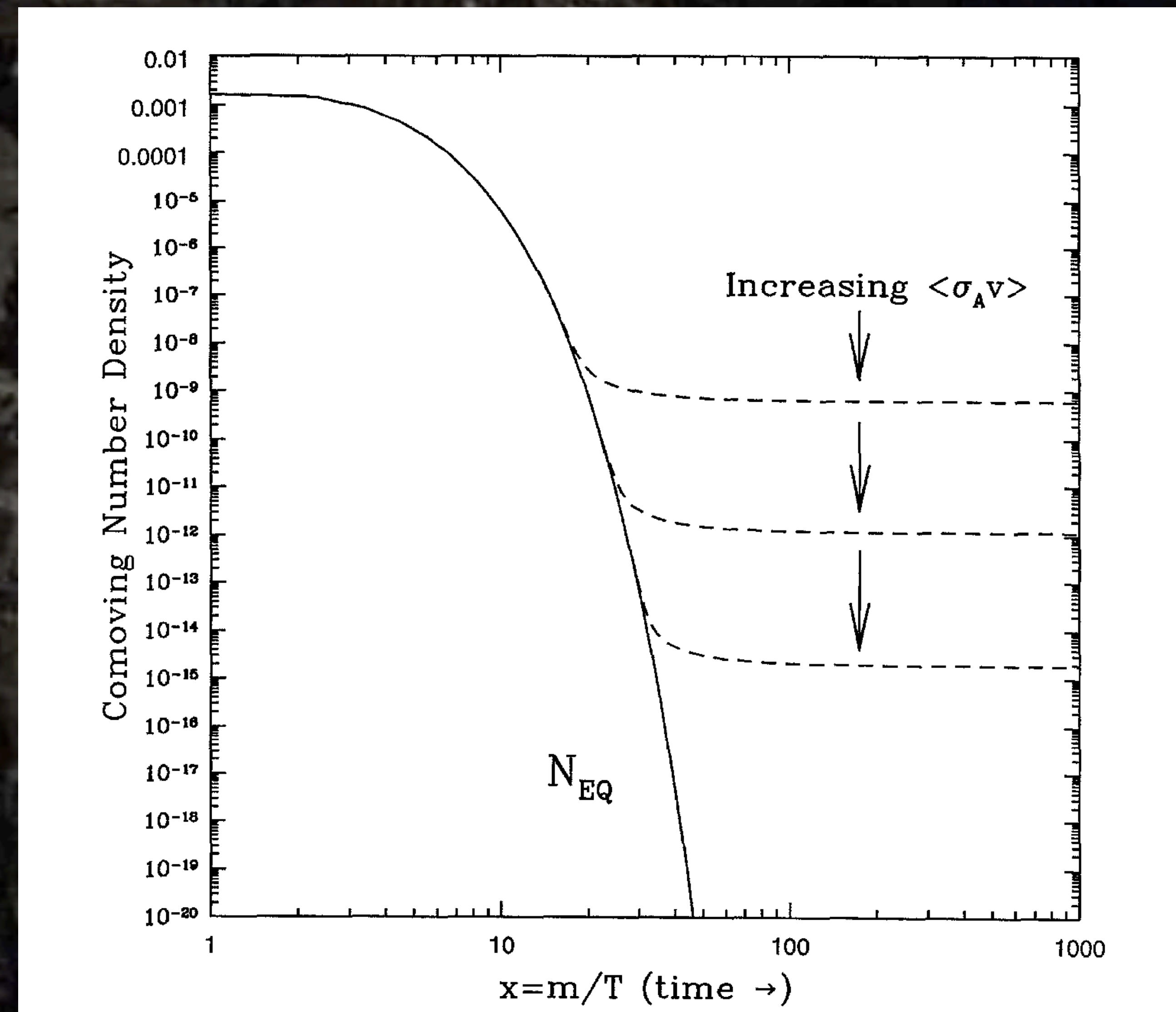

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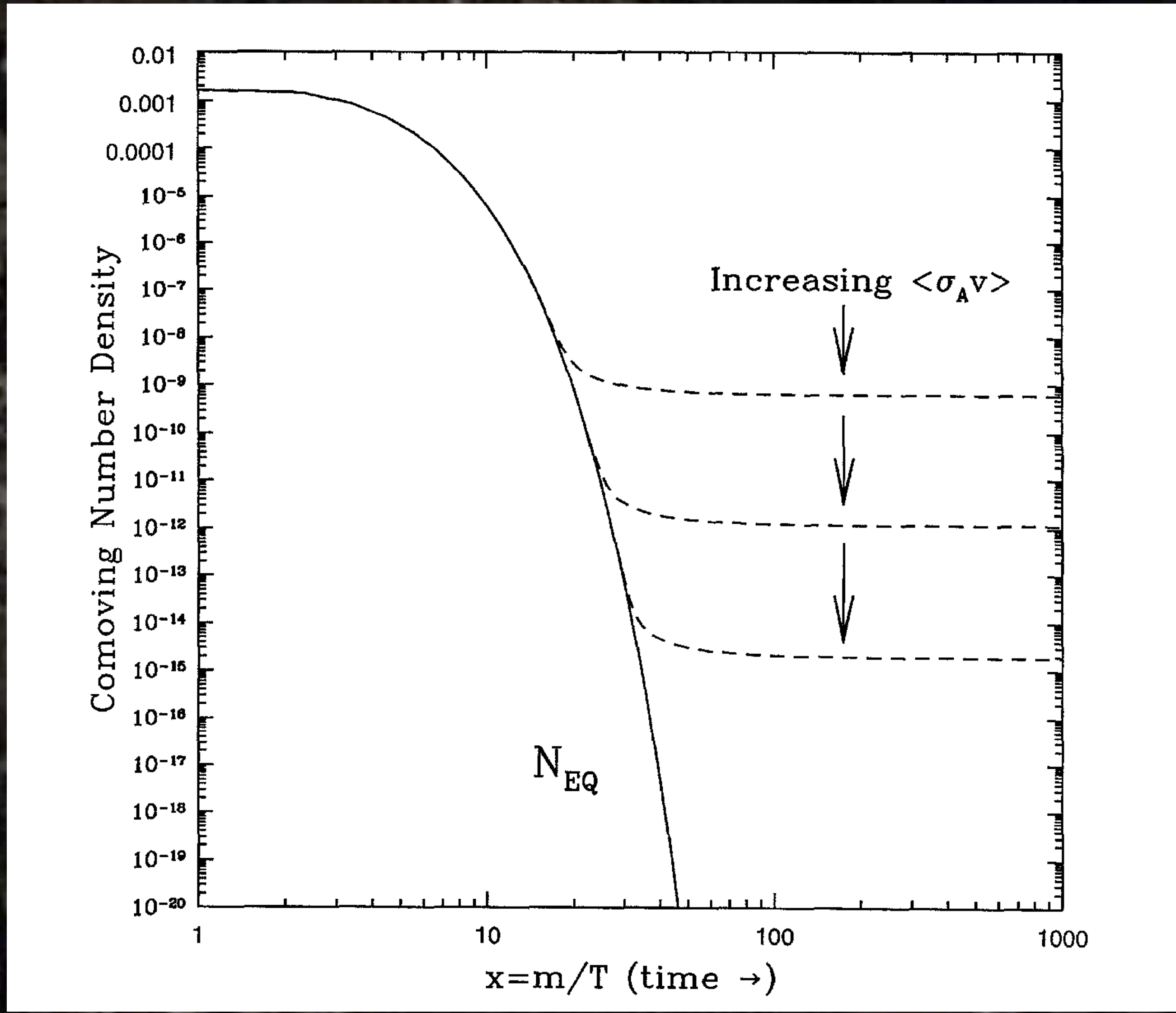

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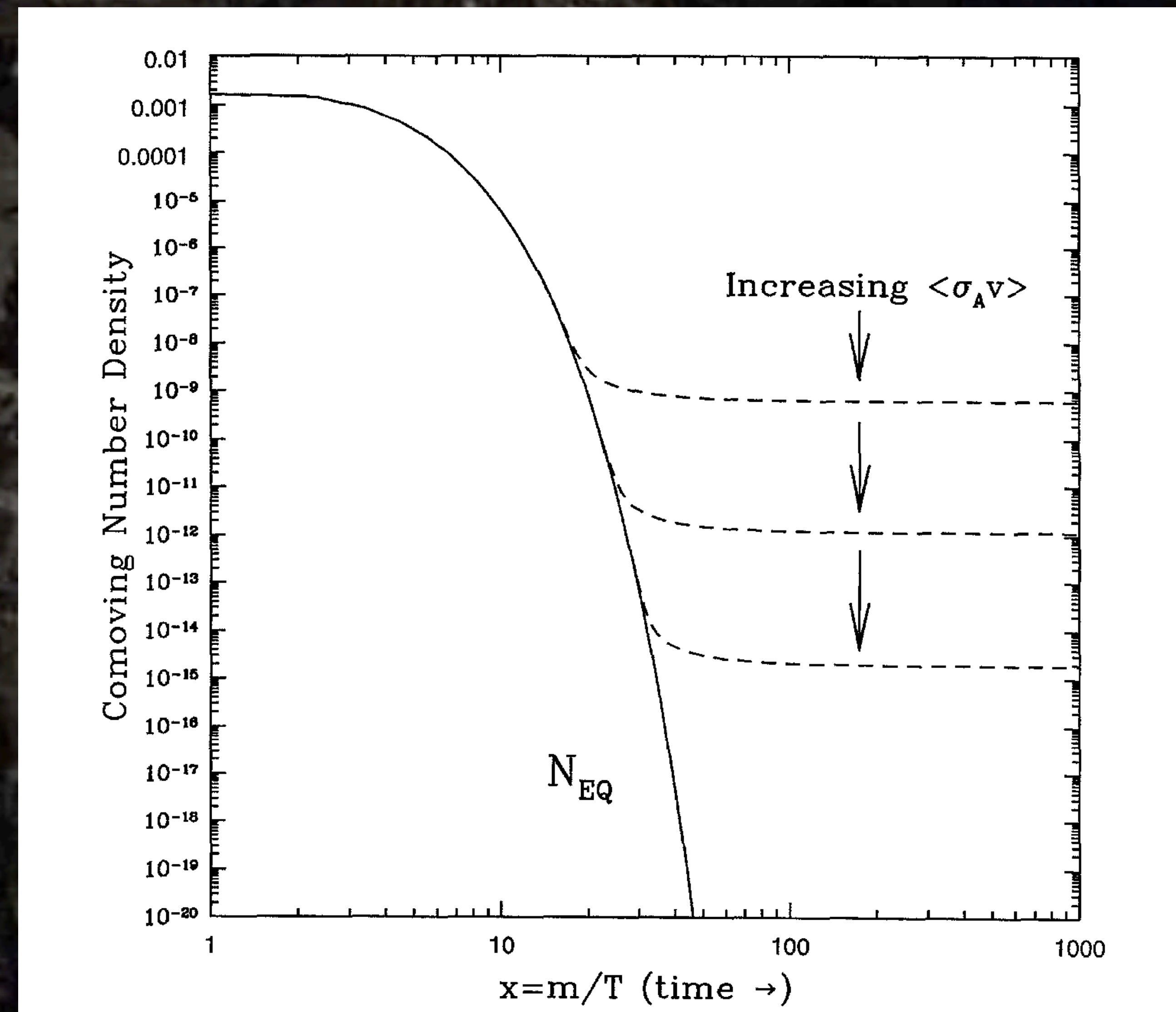

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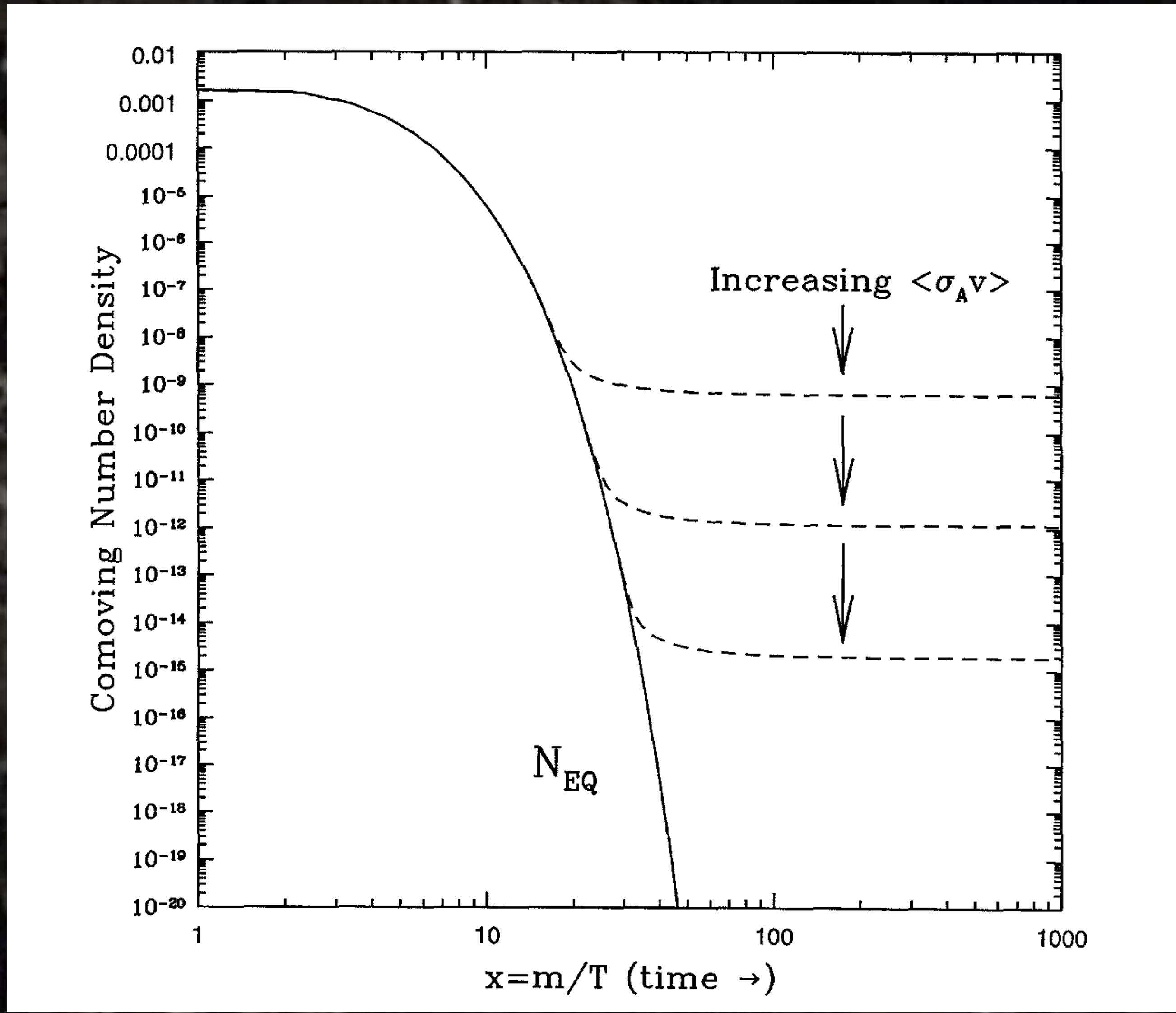

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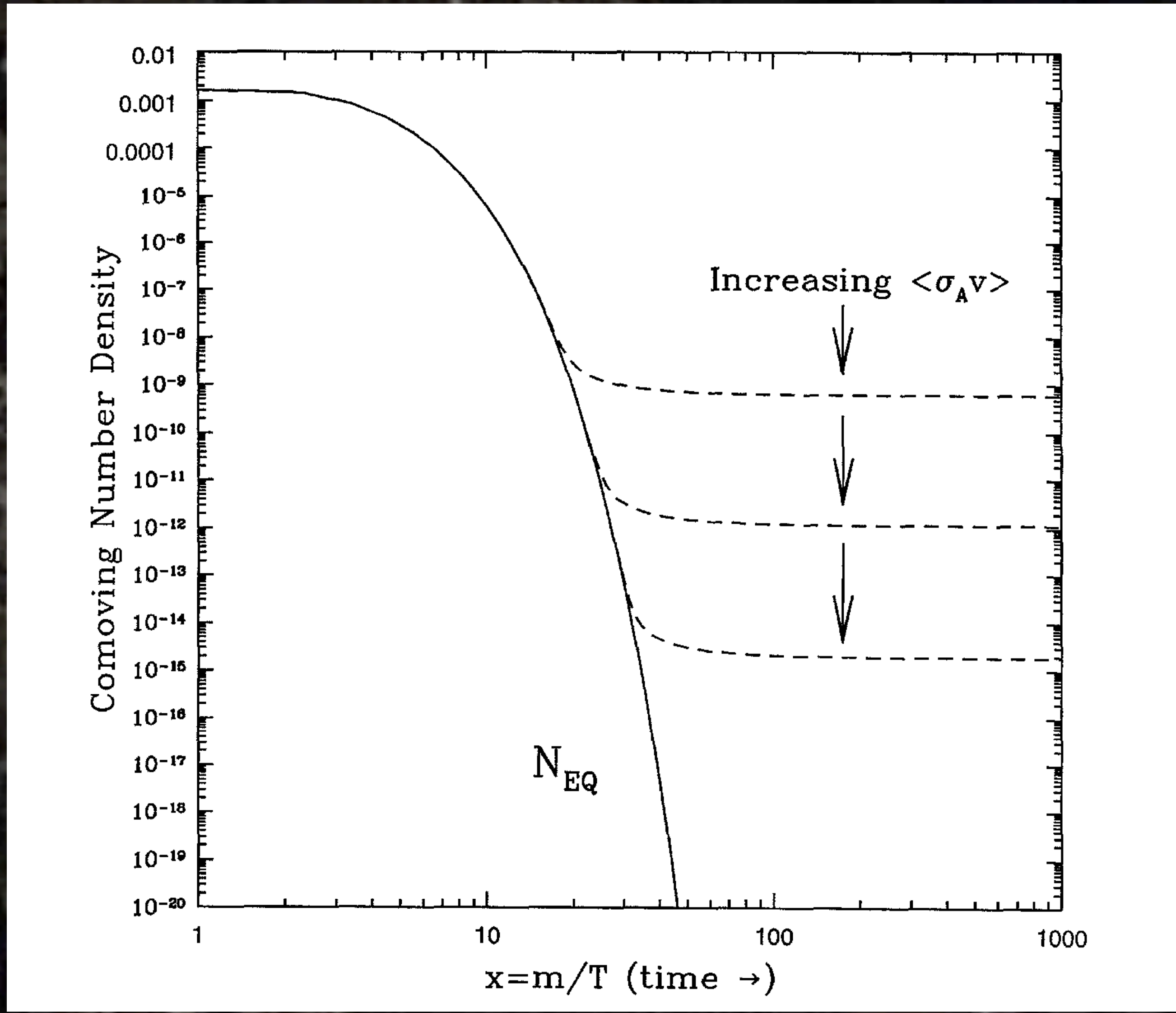

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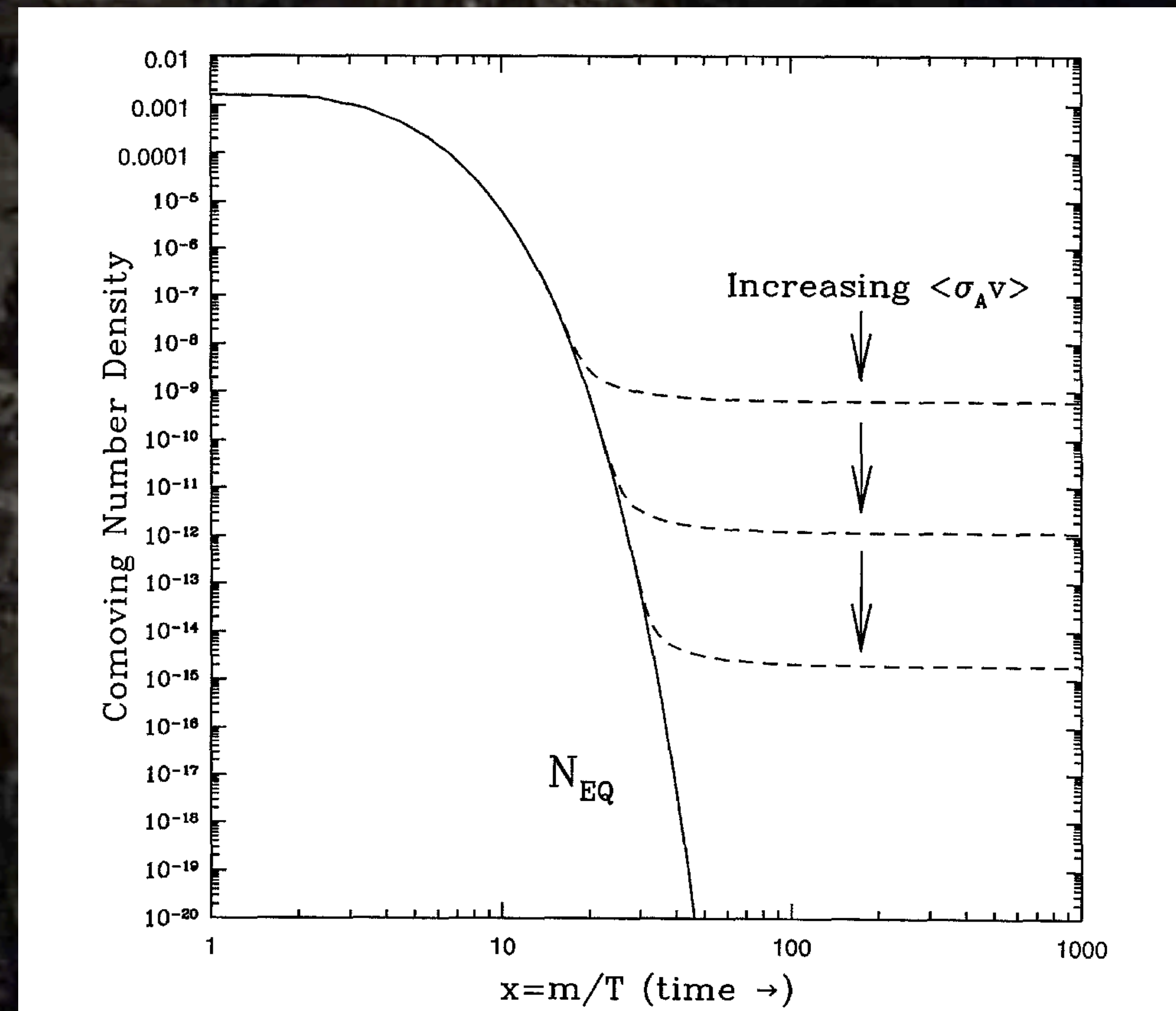
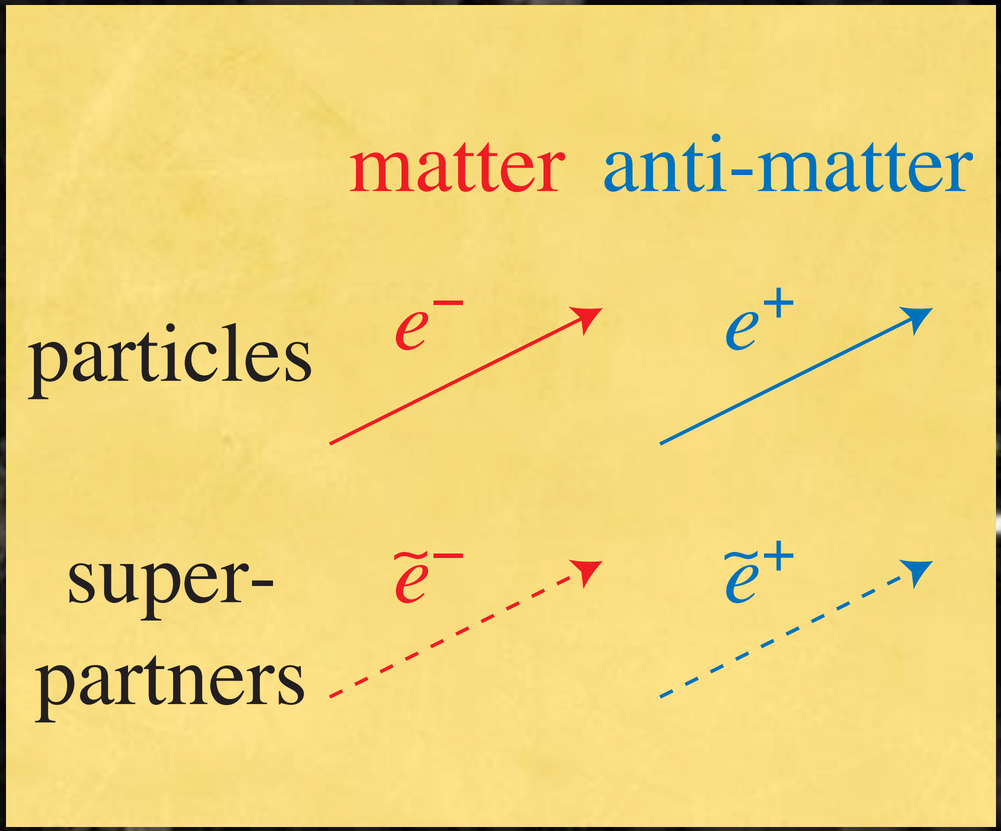


$$\Omega_M = \frac{0.756(n+1)x_f^{n+1}}{g^{1/2}\sigma_{ann} M_{Pl}^3} \frac{3s_0}{8\pi H_0^2} \approx \frac{\alpha^2/(TeV)^2}{\sigma_{ann}}$$

Quantum Dimension

- The best candidate suggested by string theory: supersymmetry
- every particle has anti-matter counterpart: doubled the number
- Nature may do it again
- The lightest superparticle is stable, neutral, weakly interacting

$\Rightarrow$ Dark Matter candidate



Listening to Faint Sound

Listening to Faint Sound

Can't hear subtle intonation

Listening to Faint Sound

Can’t hear subtle intonation

Need to be shielded from noise!

Listening to Faint Sound

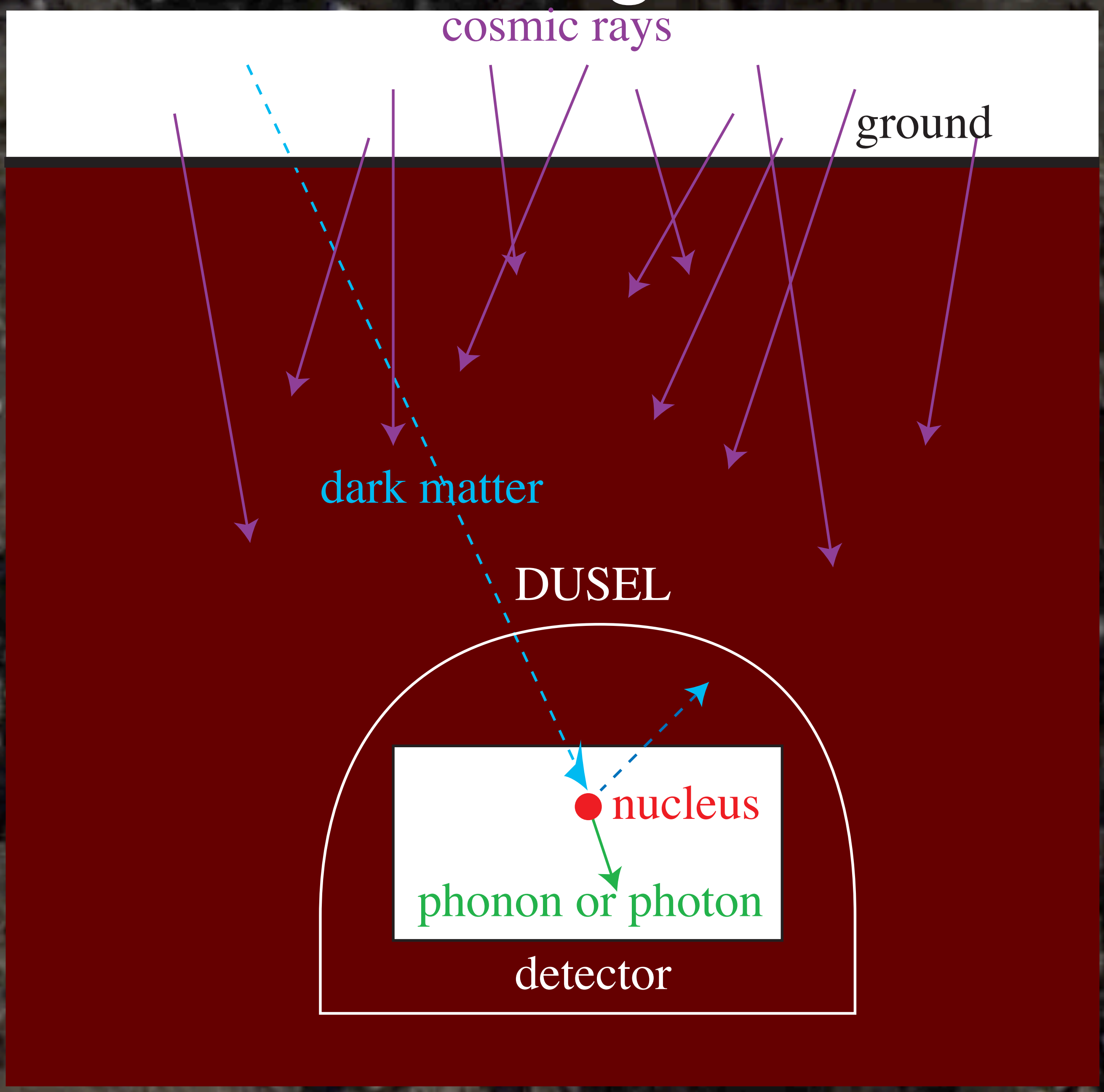
Can't hear subtle intonation

Need to be shielded from noise!

To listen to the faint sound of dark matter, go where it's quiet

Finding Dark Matter

Go underground!



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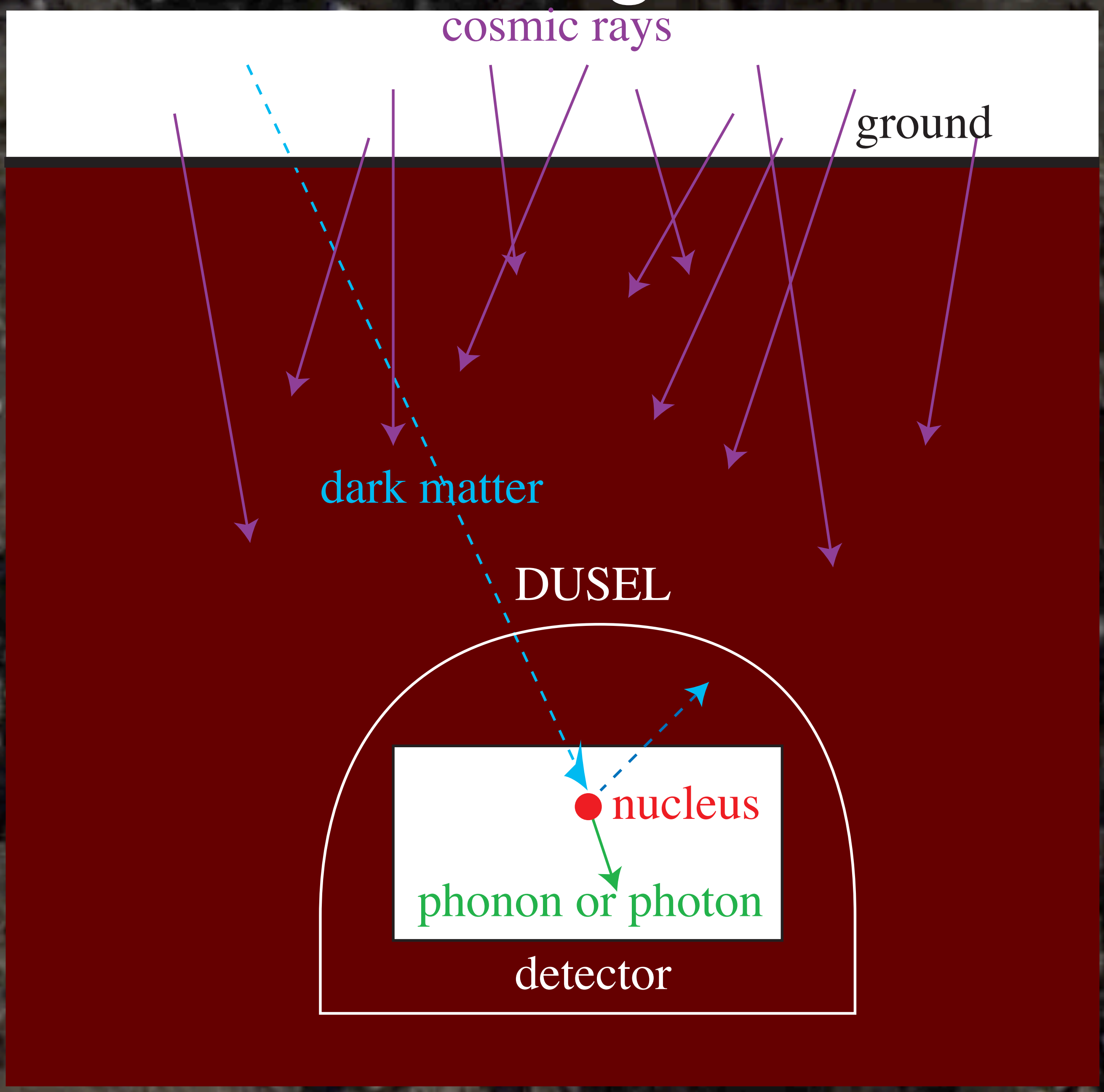

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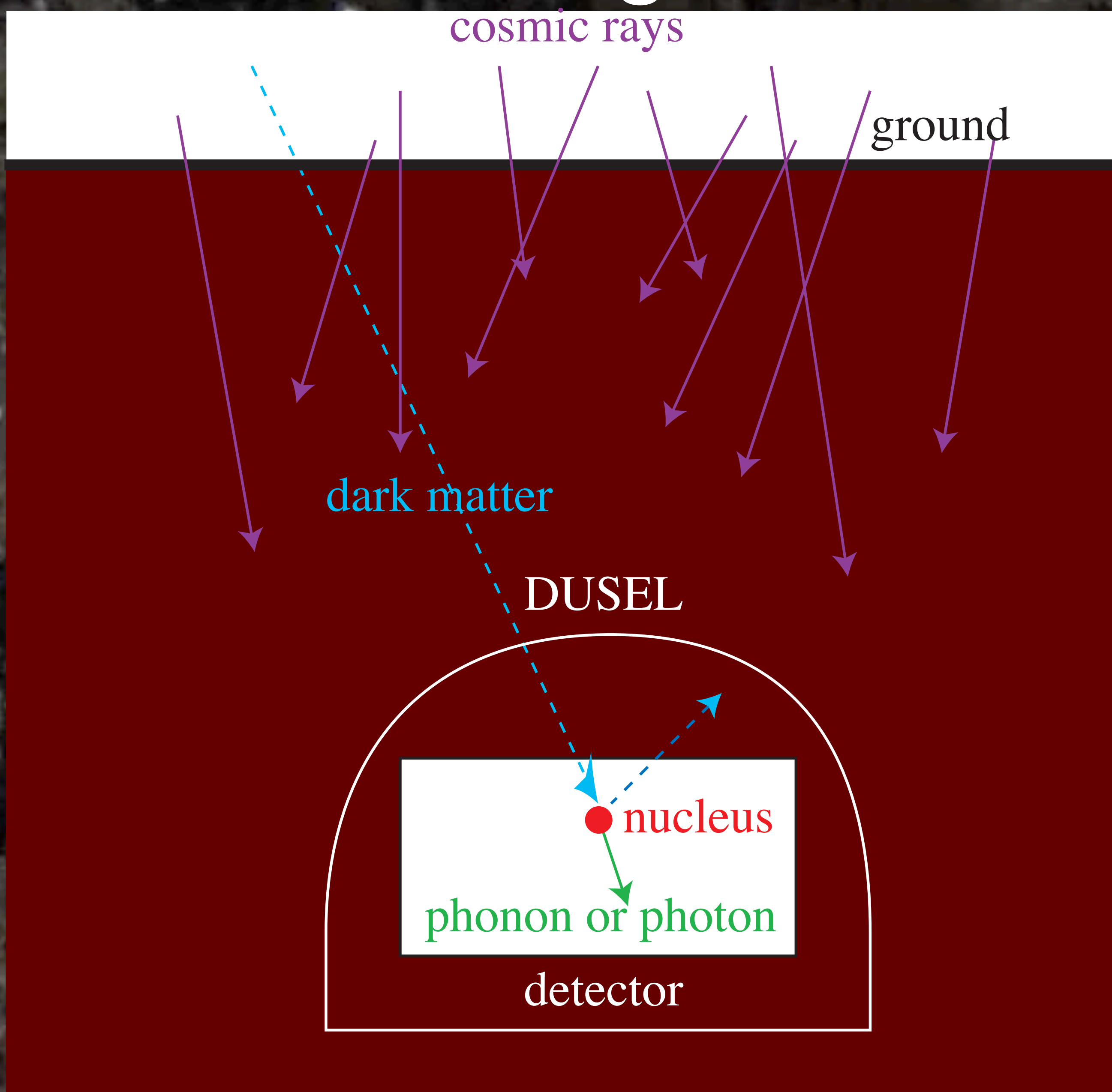
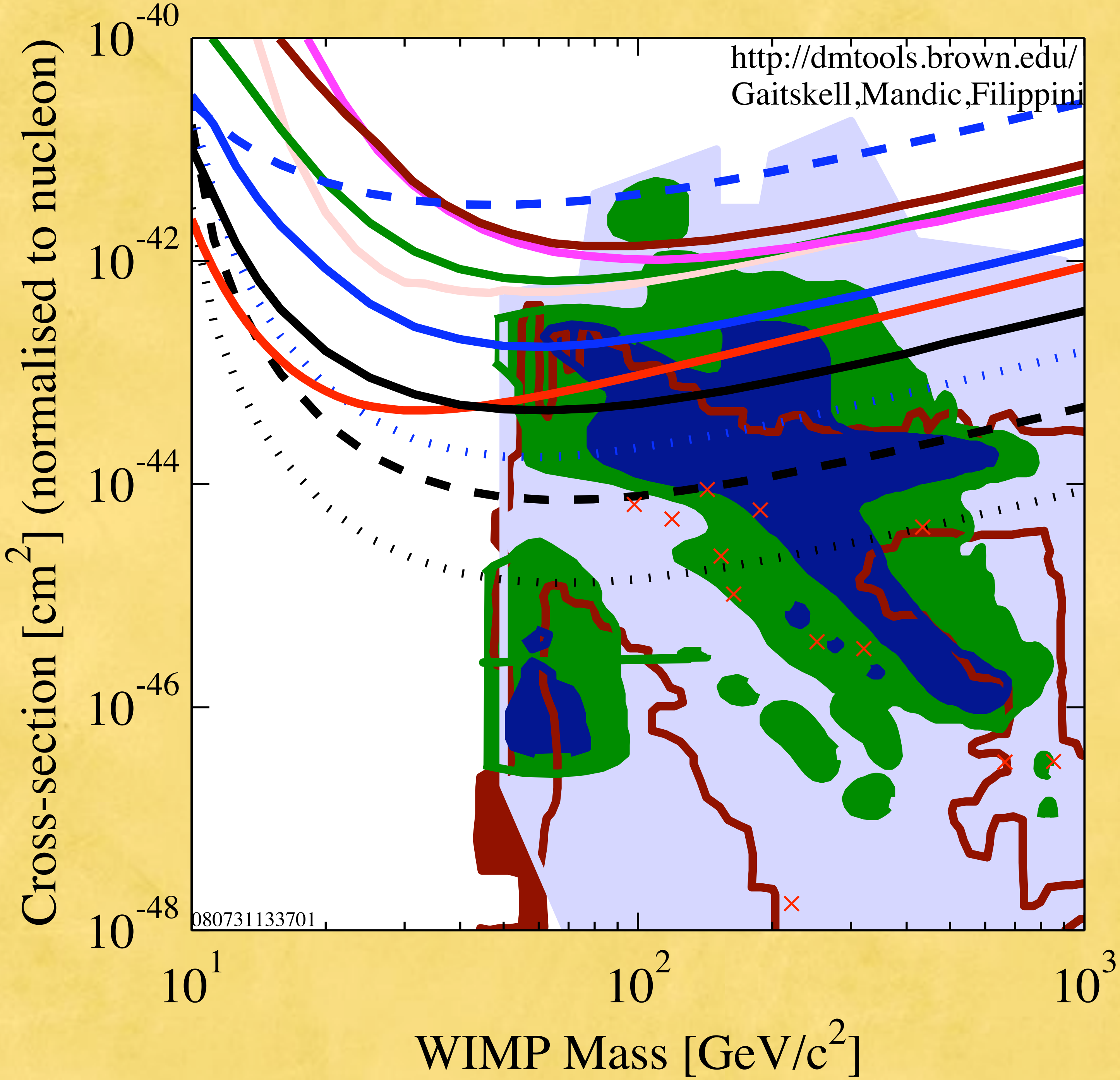
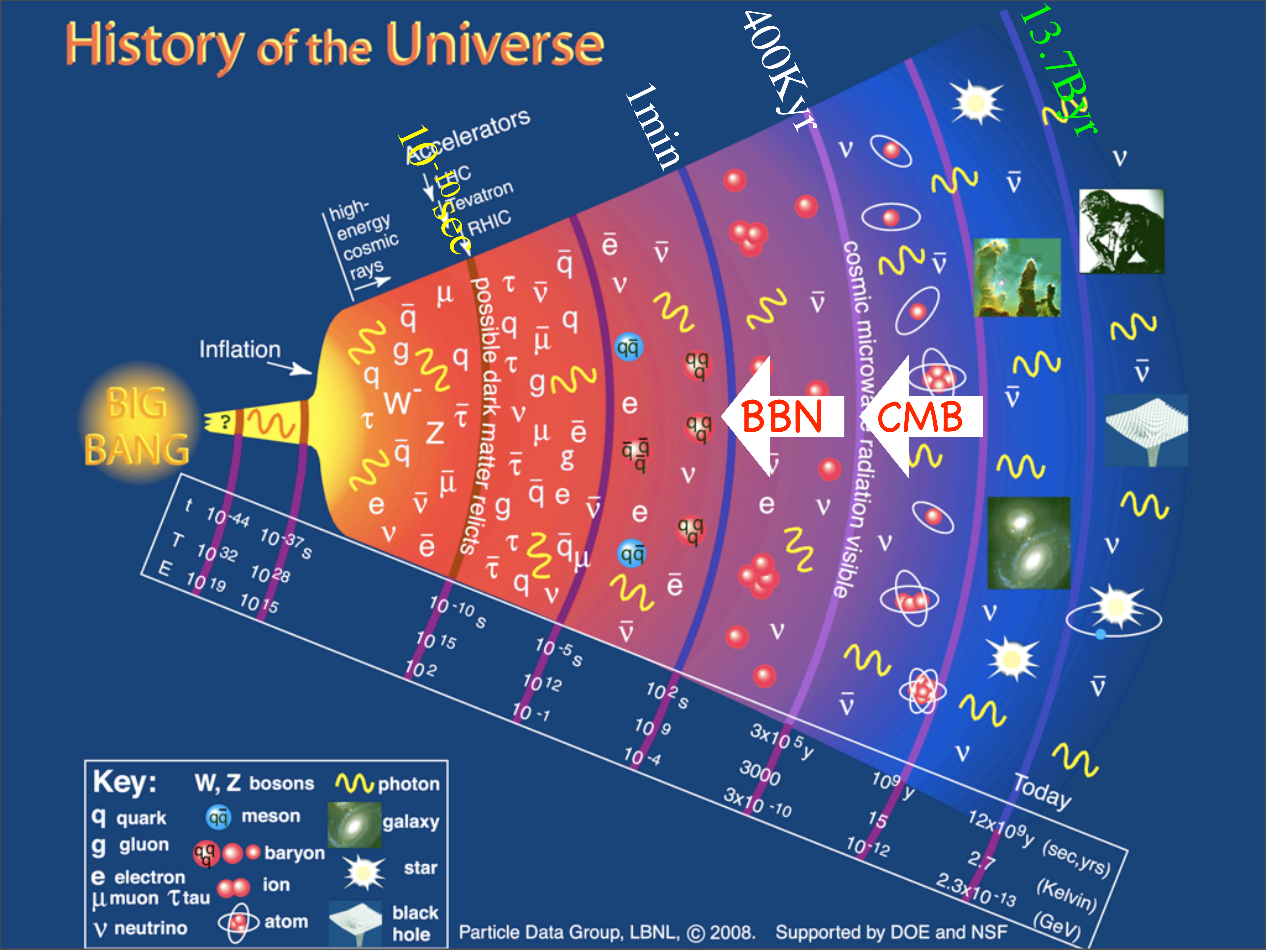


Soudan, MN: too shallow

Getting There



ZEPLIN-II, 2007
CDMS-II, 2005
XENON10, 2007
CDMS-II, 2008


History of the Universe
BIG BANG
Inflation
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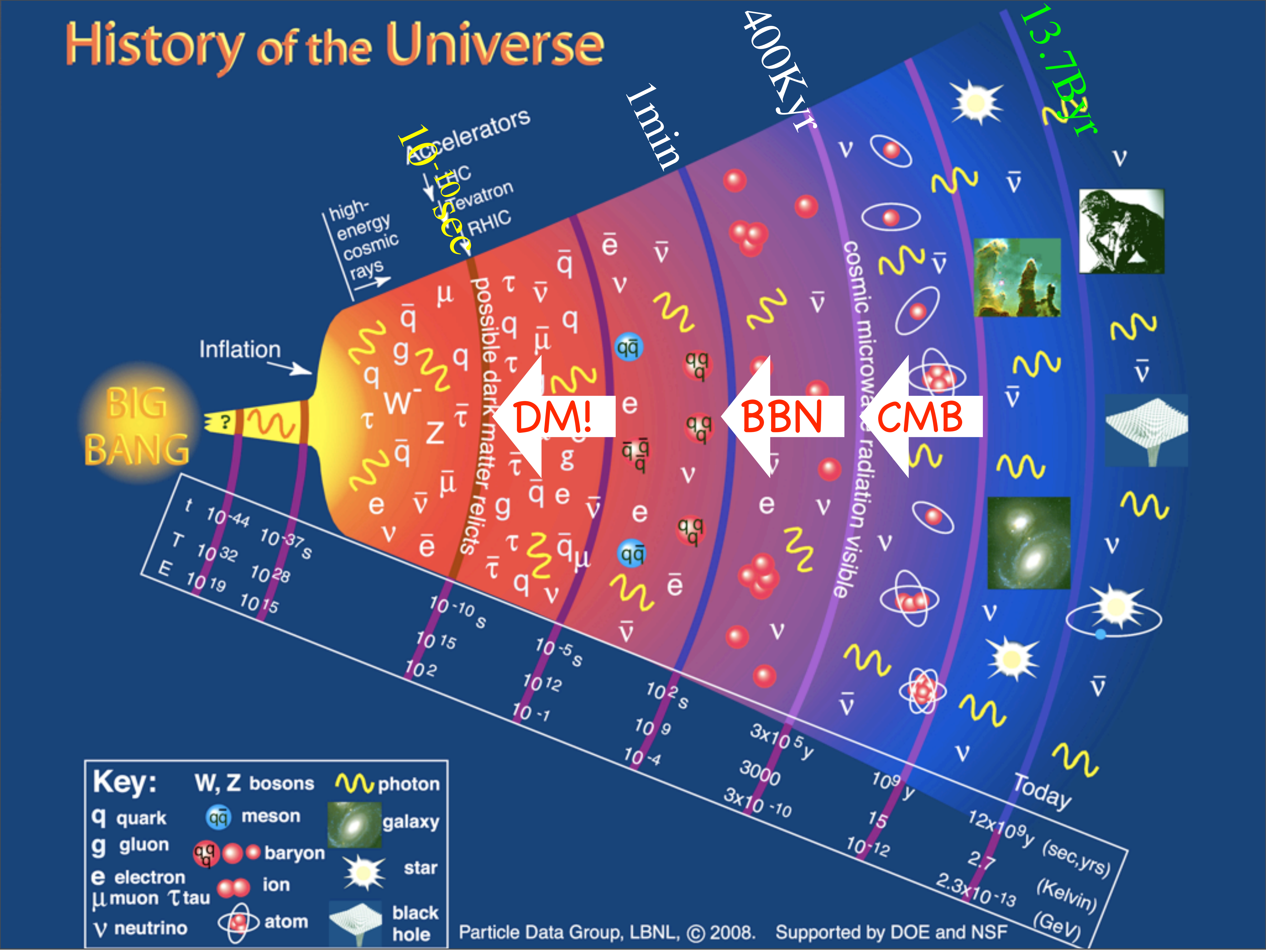
10-10 sec
1min
400Kyr
13.7Byr
possible dark matter relicts
cosmic microwave radiation visible
BBN
CMB
t 10-44 10-37 s 10-10 s 10-5 s 102 s 3x105 y 109 y Today 12x109y (sec,yrs)
T 1032 1028 1015 1012 109 3000 15 2.7 (Kelvin)
E 1019 1015 102 10-1 10-4 3x10-10 10-12 2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF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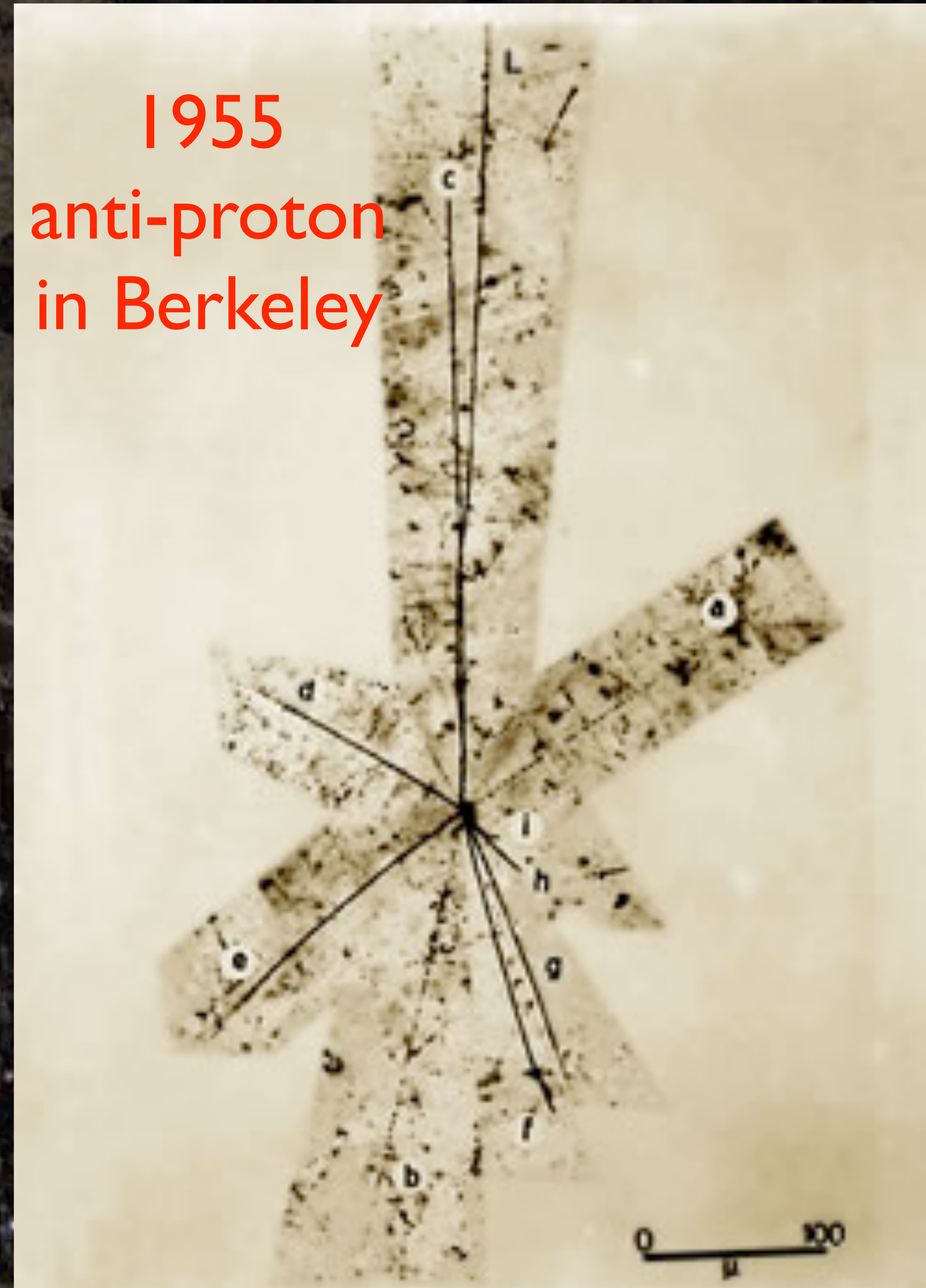
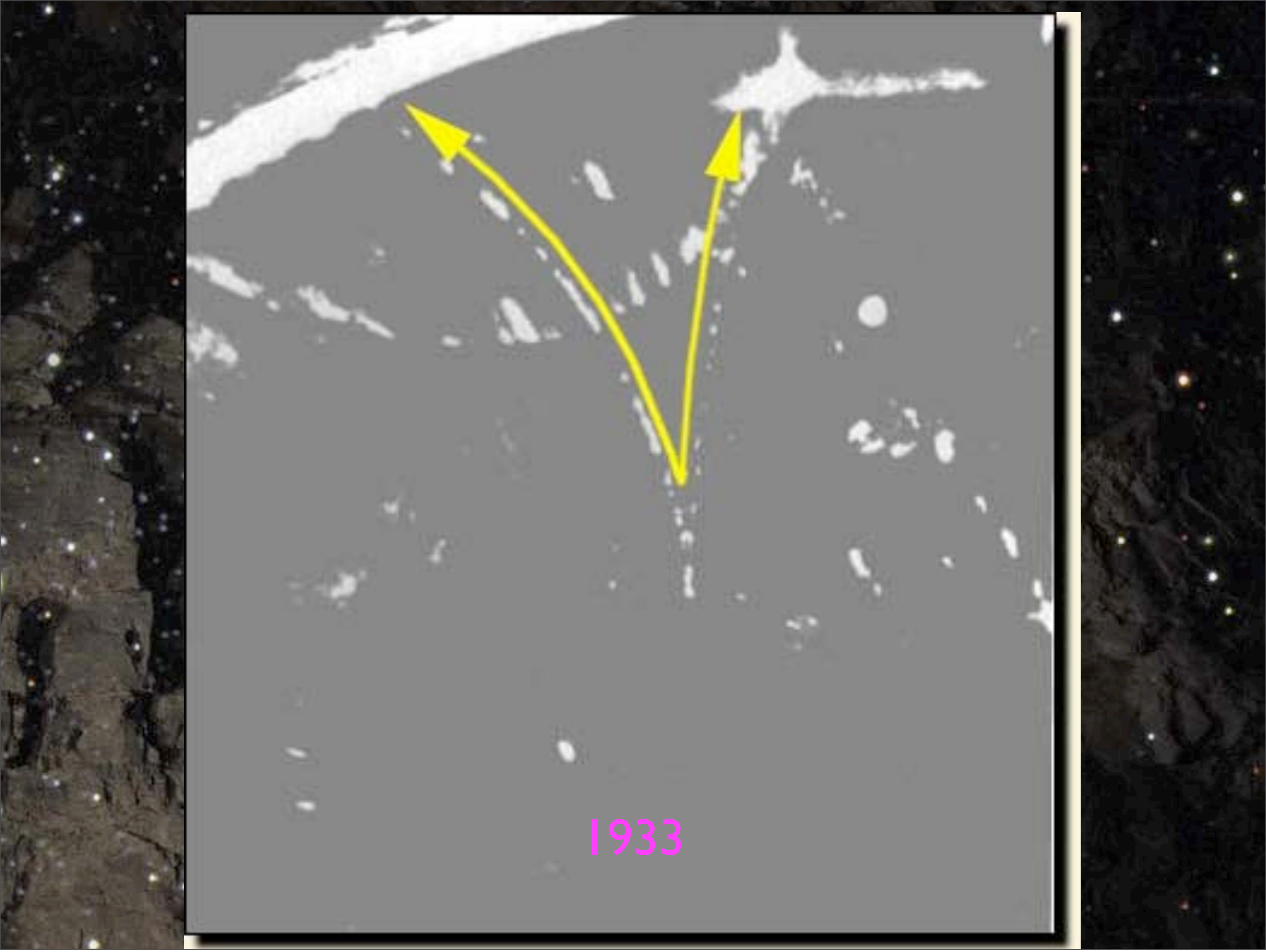
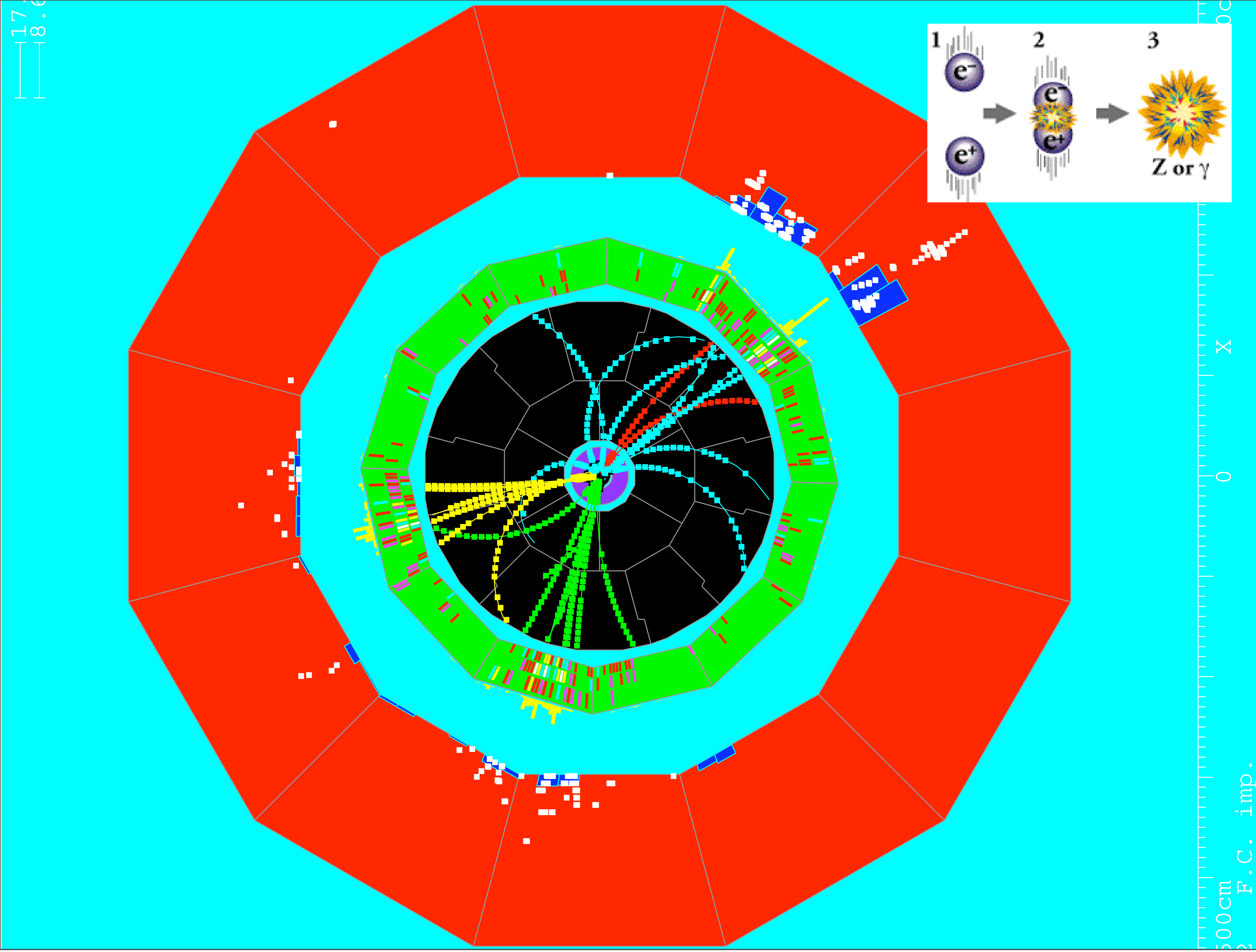
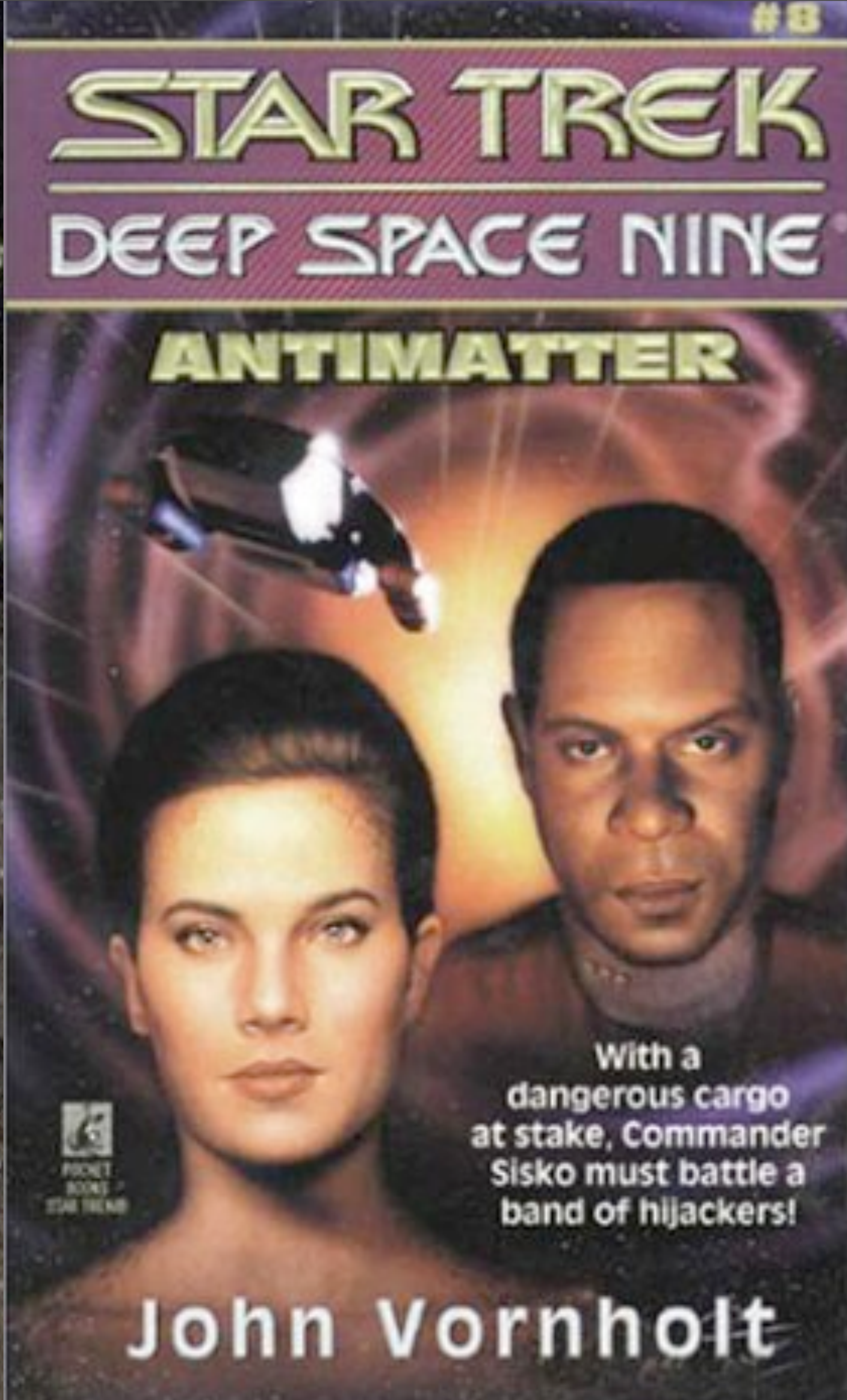
Anti-Matter

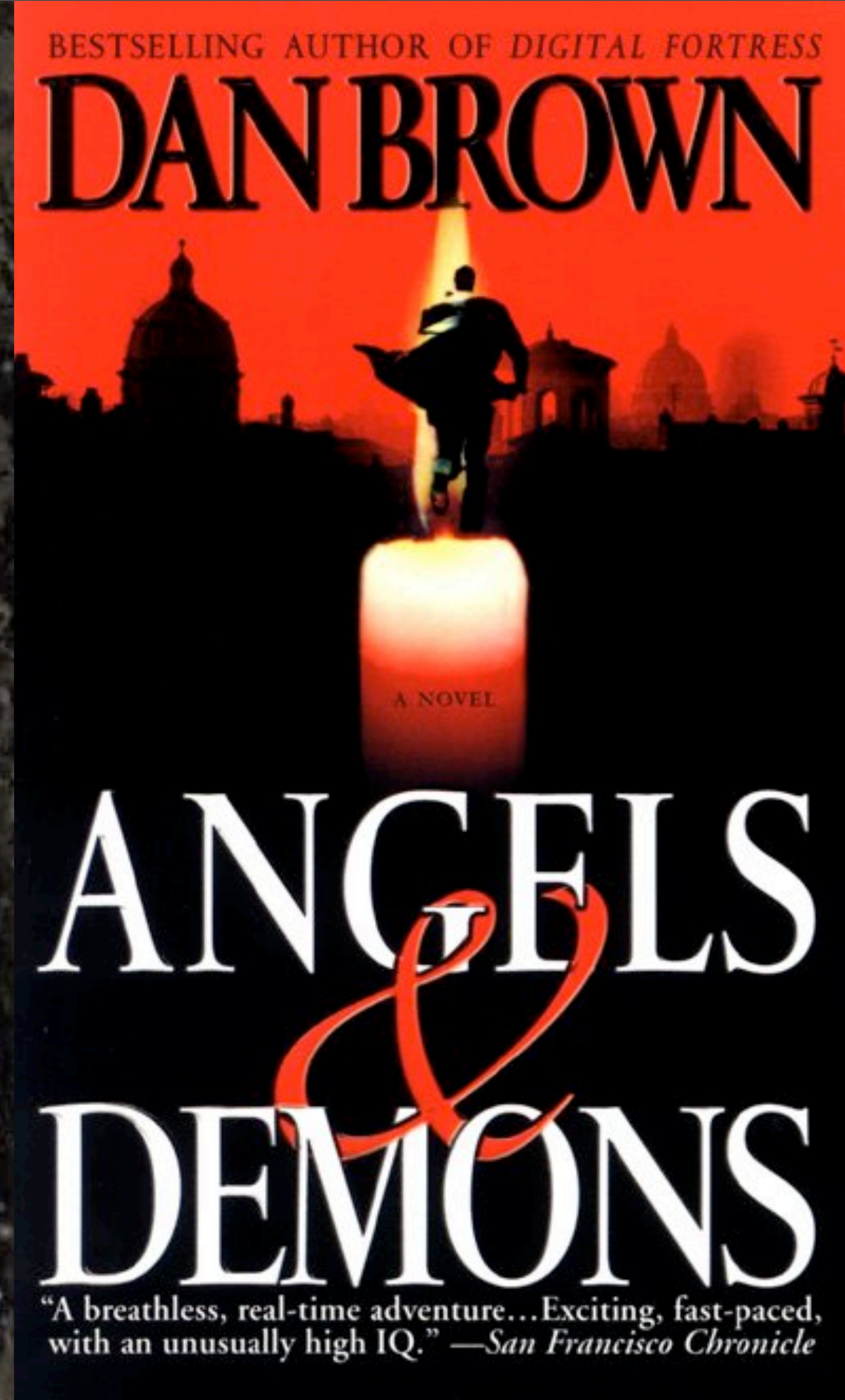
1955
anti-proton
in Berkeley




1933


1
2
3
e⁻
e⁺
Z or γ
X
0
F.C. imp.


#8
STAR TREK
DEEP SPACE NINE
ANTIMATTER
With a dangerous cargo at stake, Commander Sisko must battle a band of hijackers!
John Vornholt


BESTSELLING AUTHOR OF DIGITAL FORTRESS
DAN BROWN
A NOVEL
ANGELS & DEMONS
"A breathless, real-time adventure…Exciting, fast-paced, with an unusually high IQ." —San Francisco Chronicle

Matter and Anti-Matter Early Universe

Matter and Anti-Matter
Current Universe

I

us

matter *anti-matter*

The Great Annihilation

Baryo-Genesis

Baryo-Genesis

- How did we survive the Great Annihilation?

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⇒ the search is on!

Proton Decay

- If matter and anti-matter transform to each other, maybe $p \to e^{+}$+light

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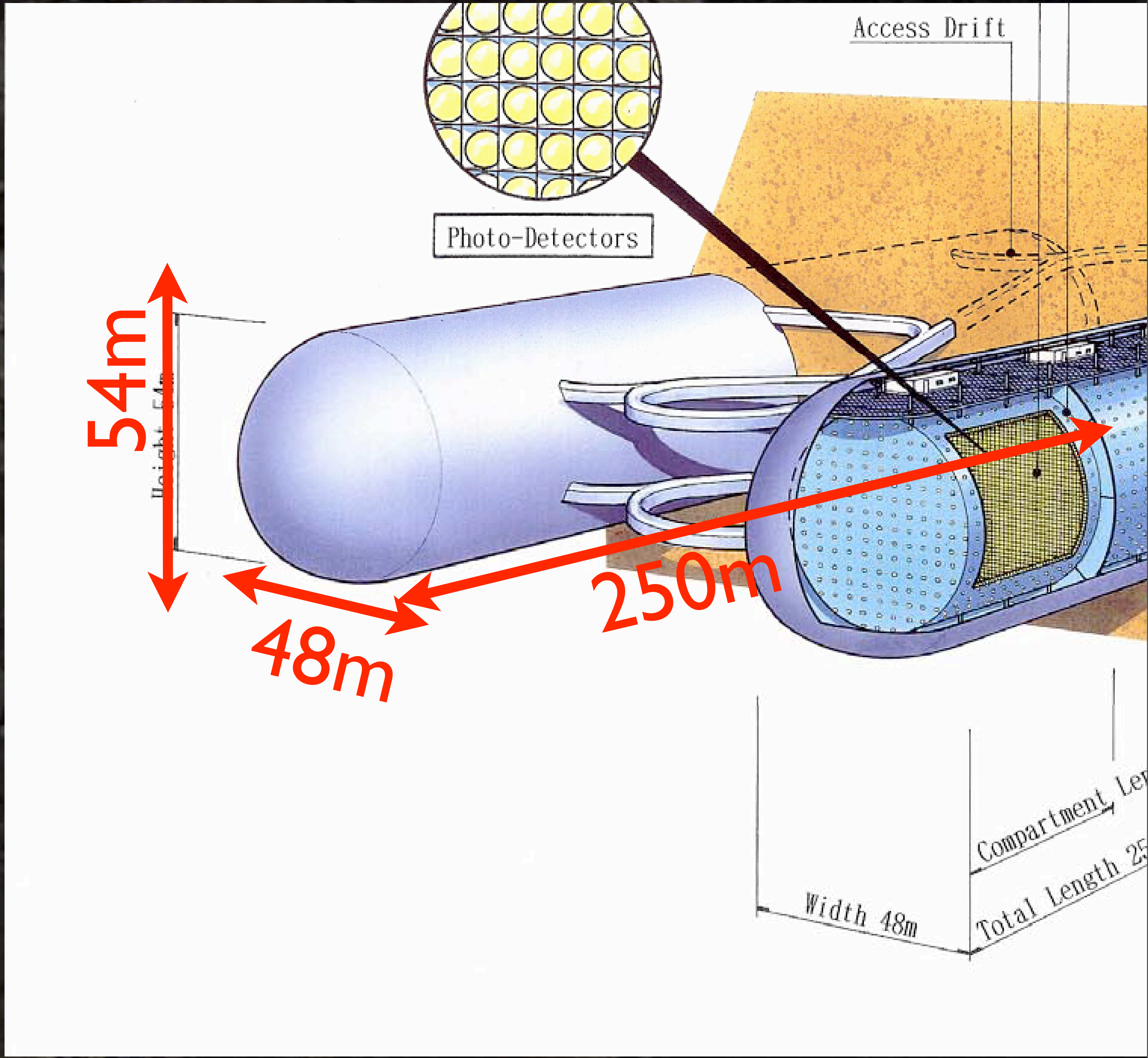

Neutrinoless Double-beta Decay

- Can anti-matter turn into matter?
- Maybe anti-neutrino can turn into neutrino because they don't carry electricity!
- 0νββ: $nn \rightarrow ppe^{-}e^{-}$ with no neutrinos
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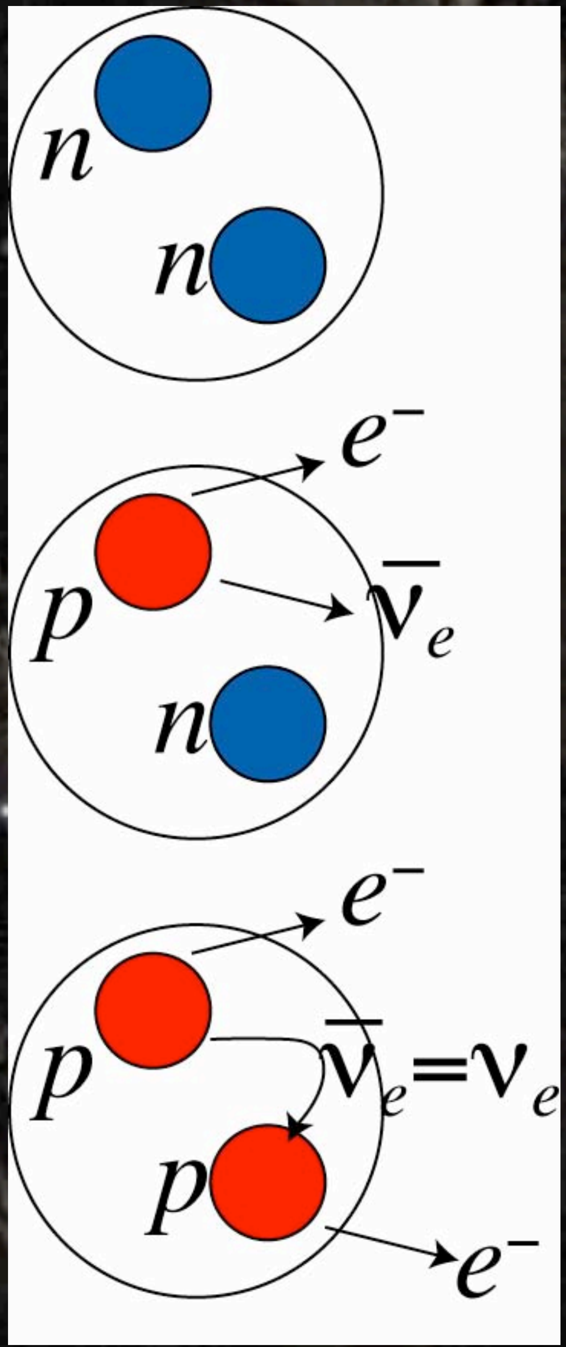

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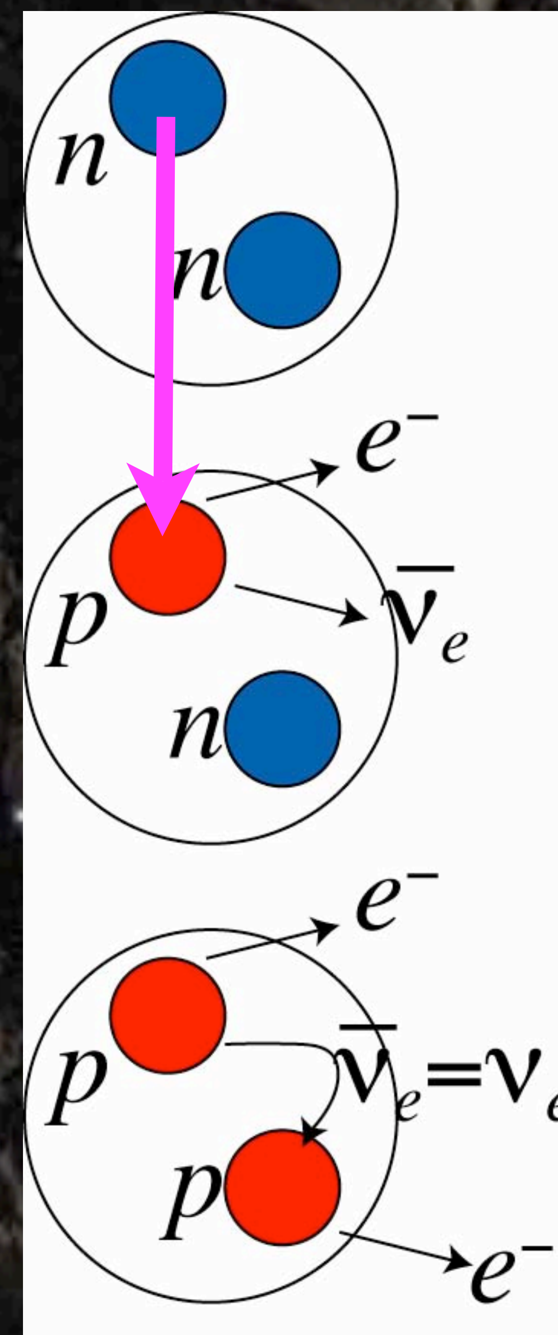

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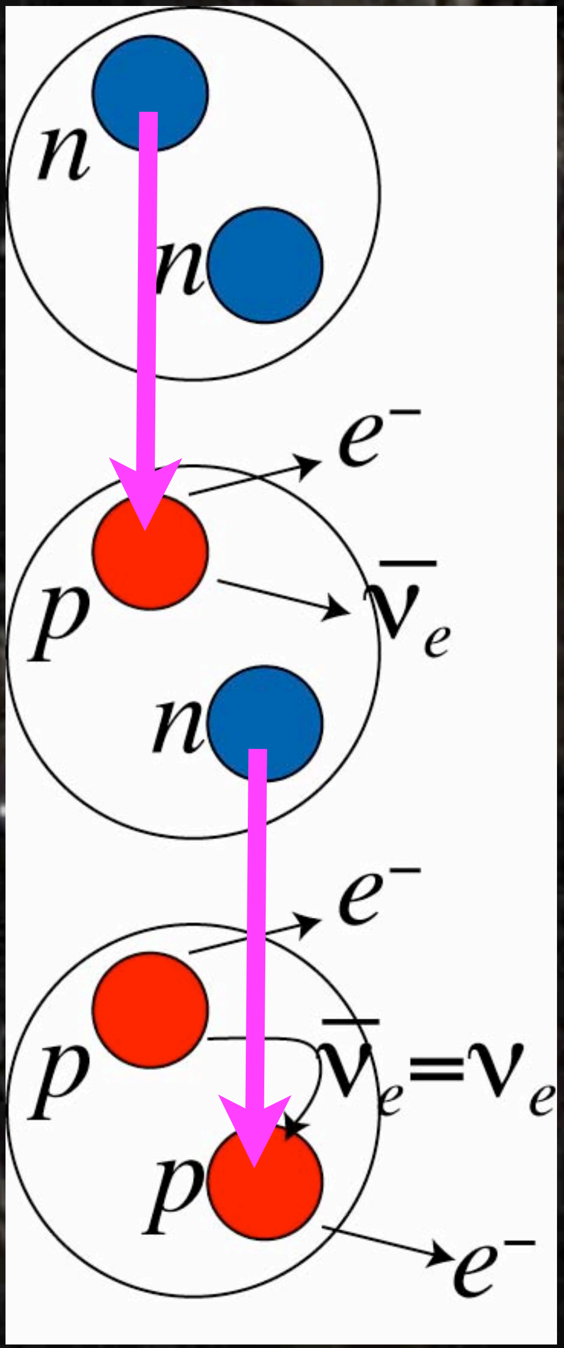

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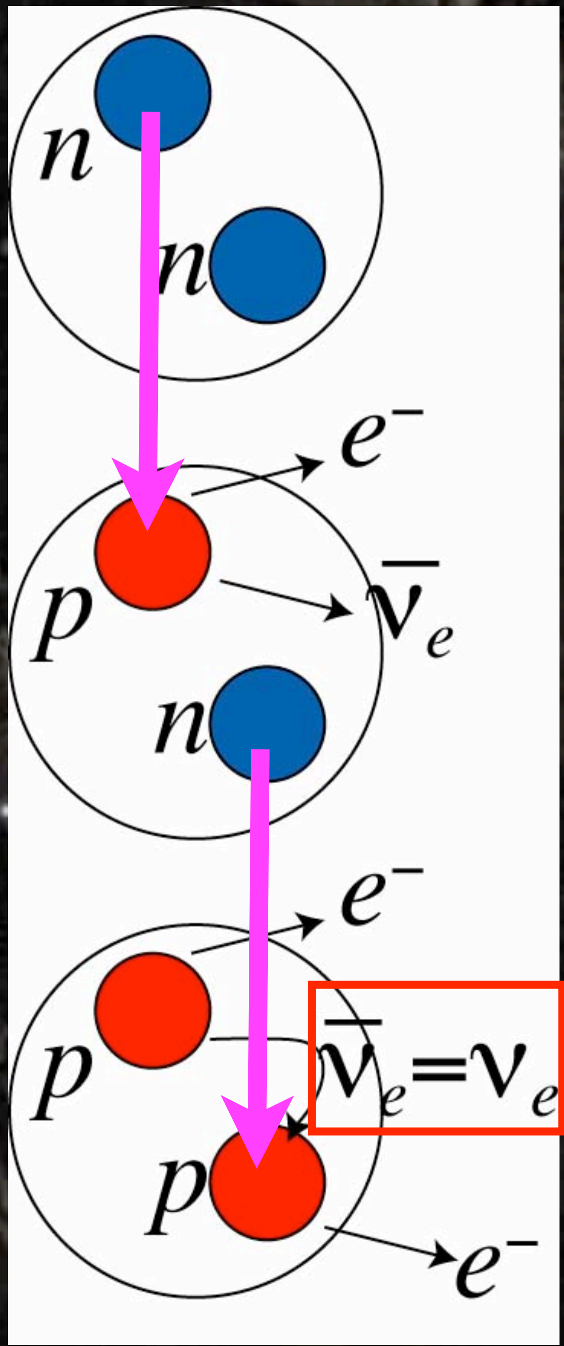

41

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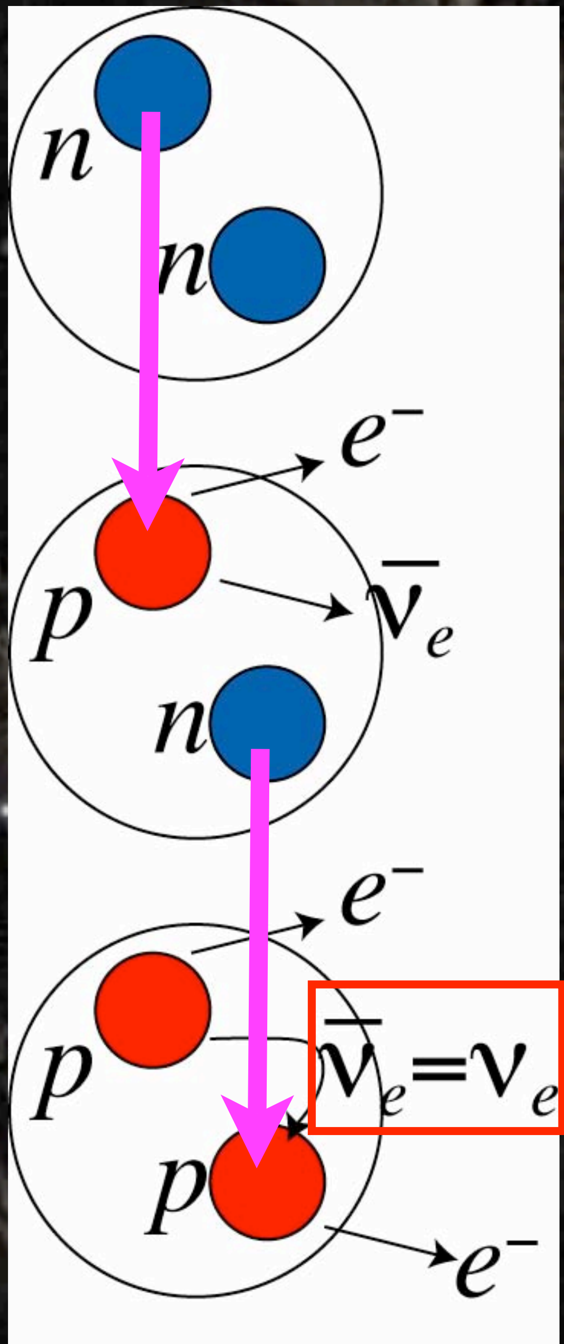
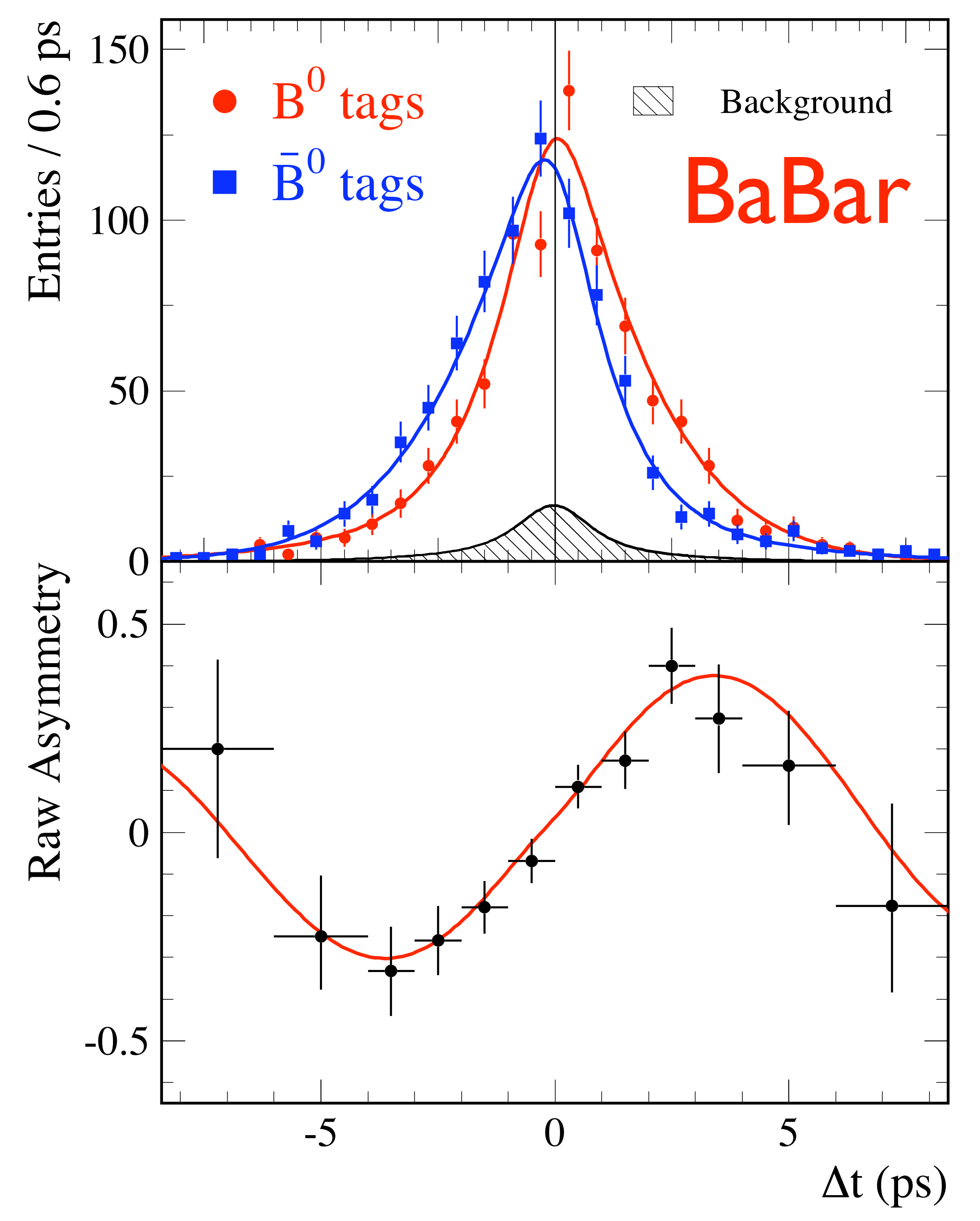


Also n-$\bar{n}$ oscillation

CP Violation



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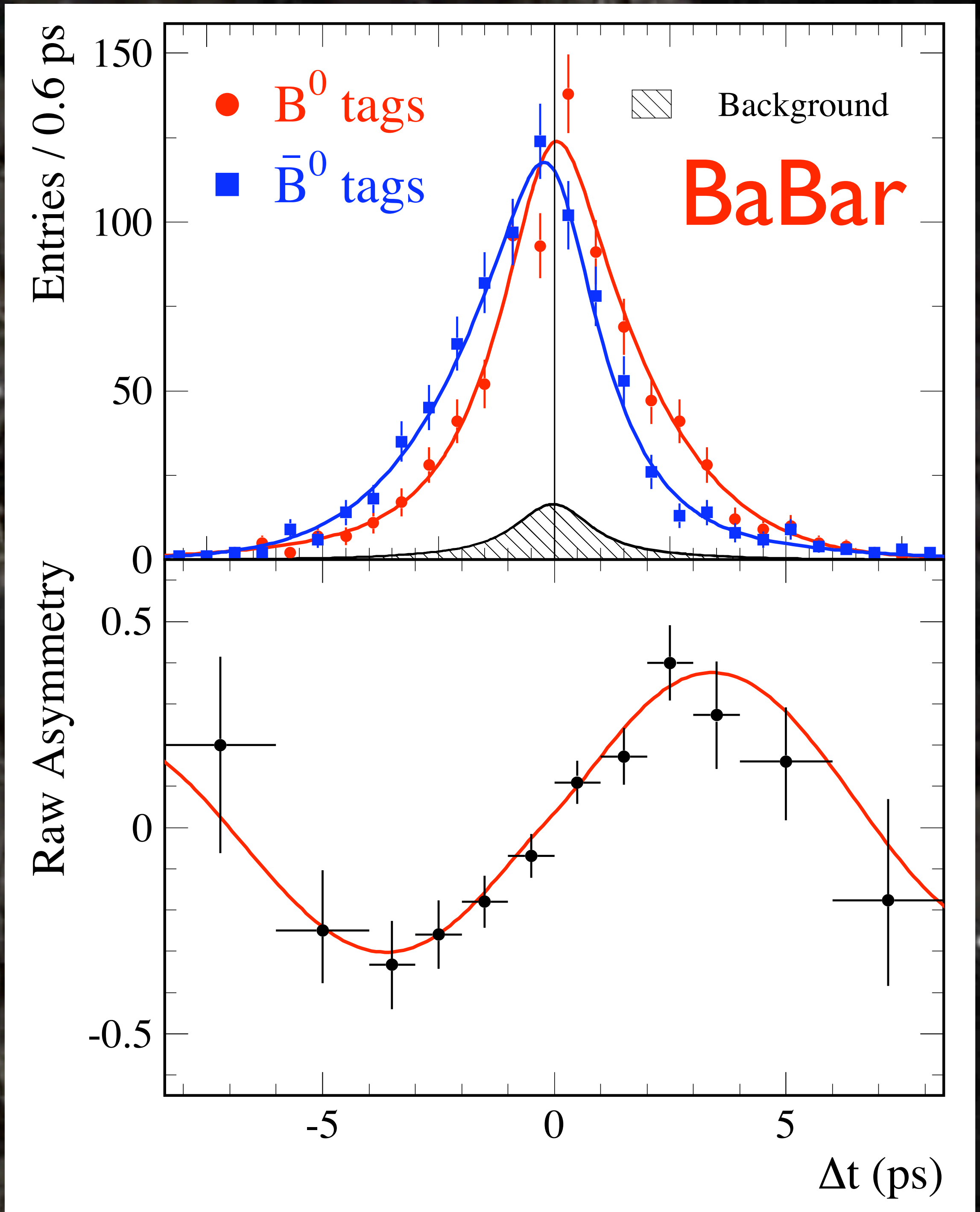

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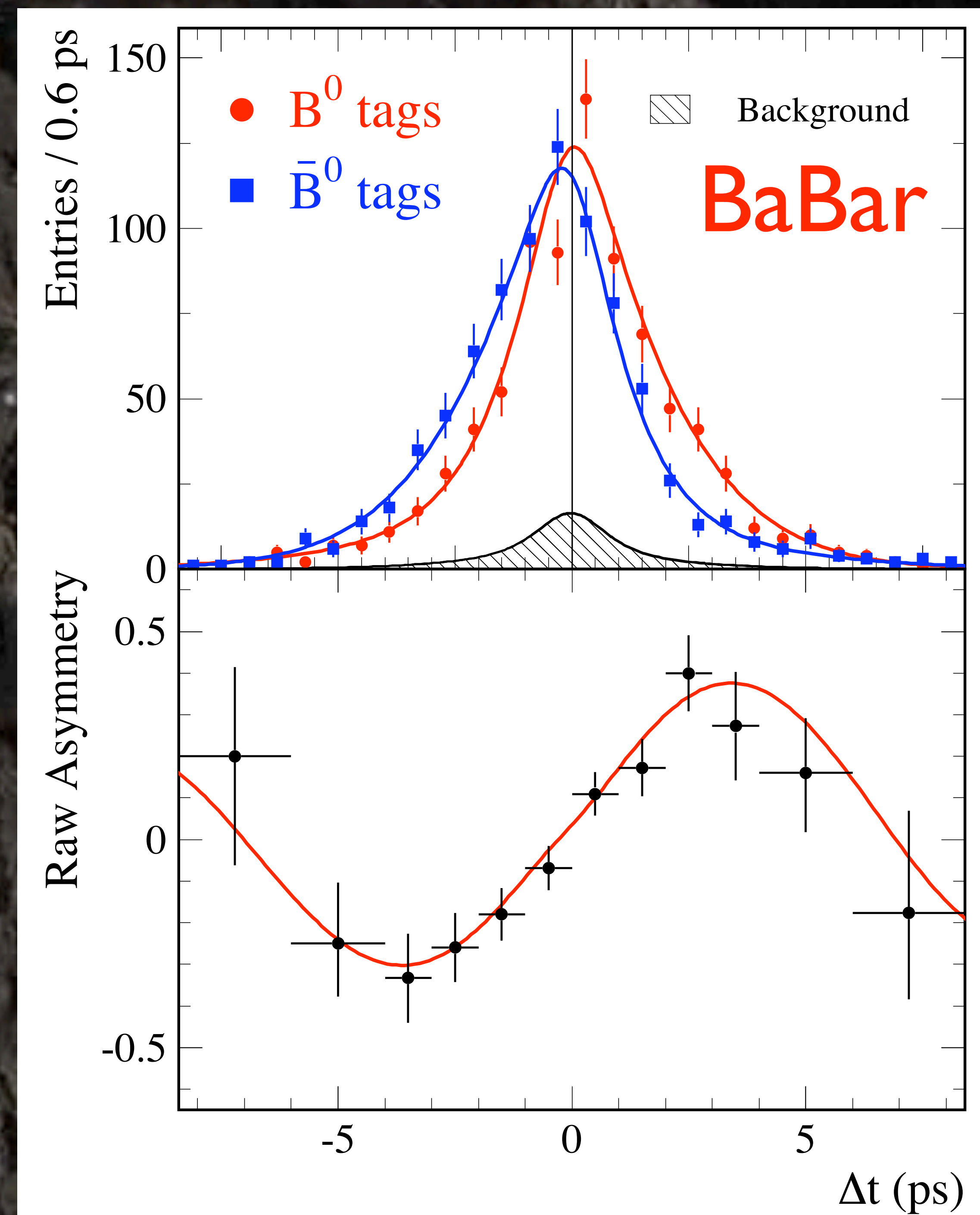

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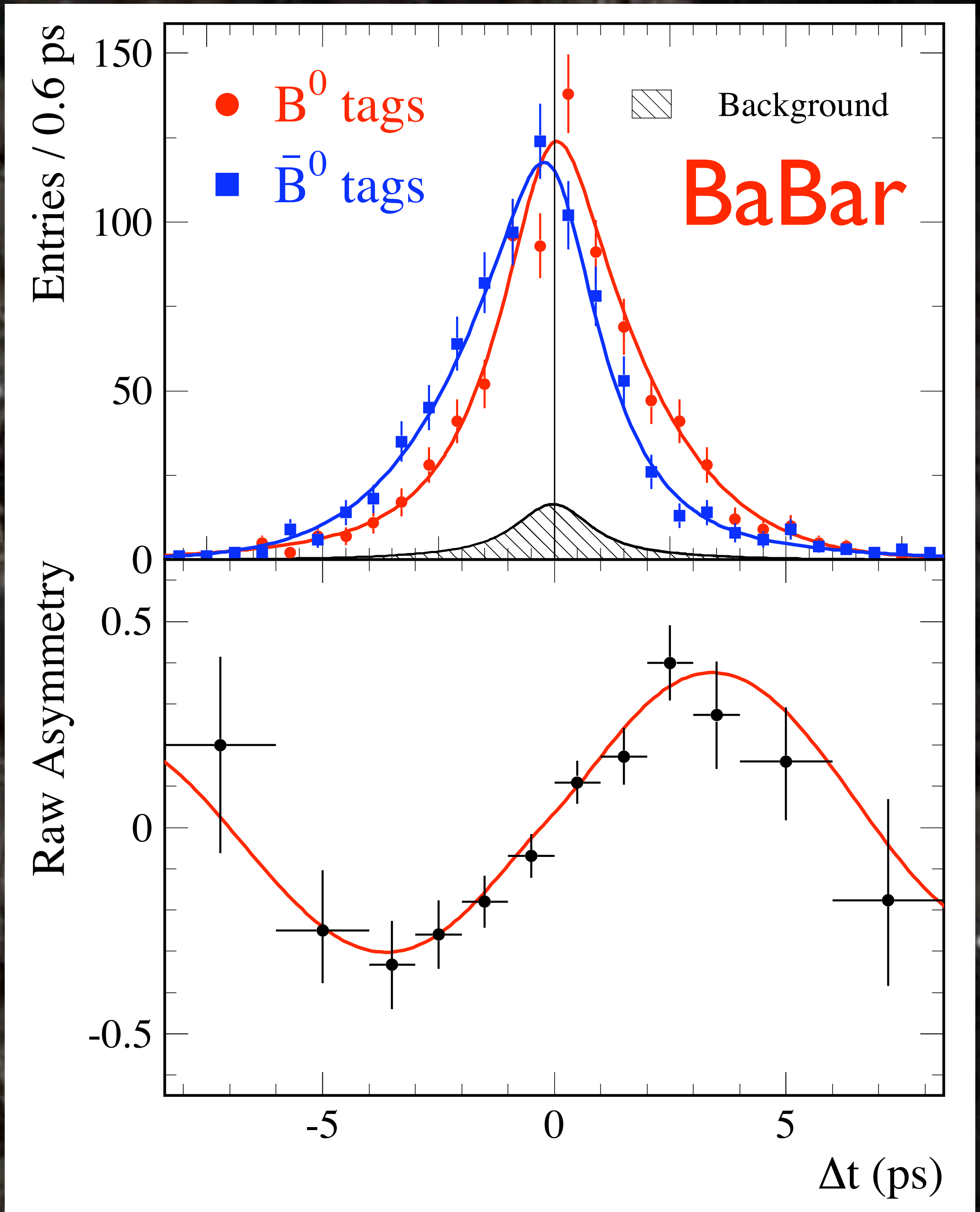

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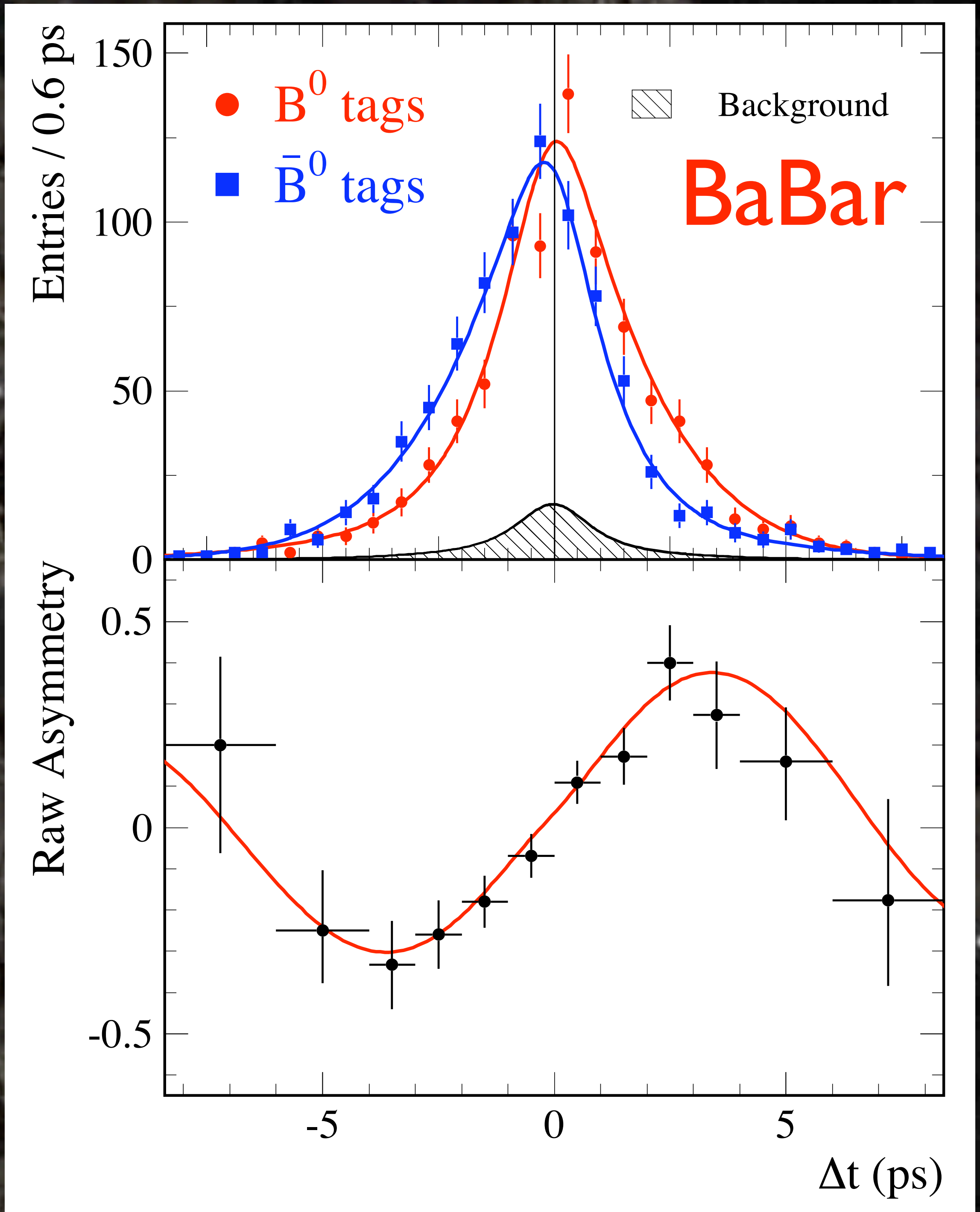

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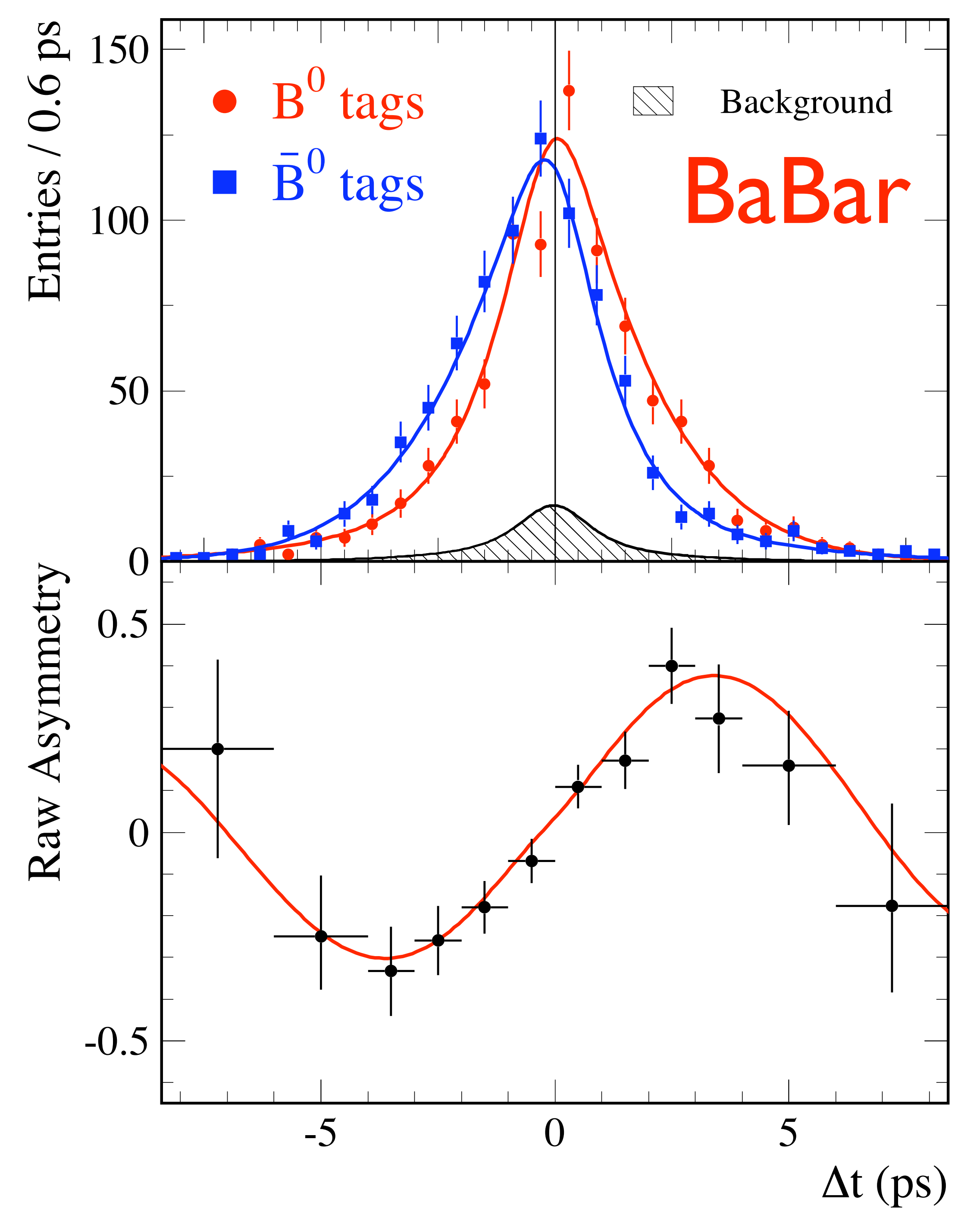

Nobel Prize in Physics 2008

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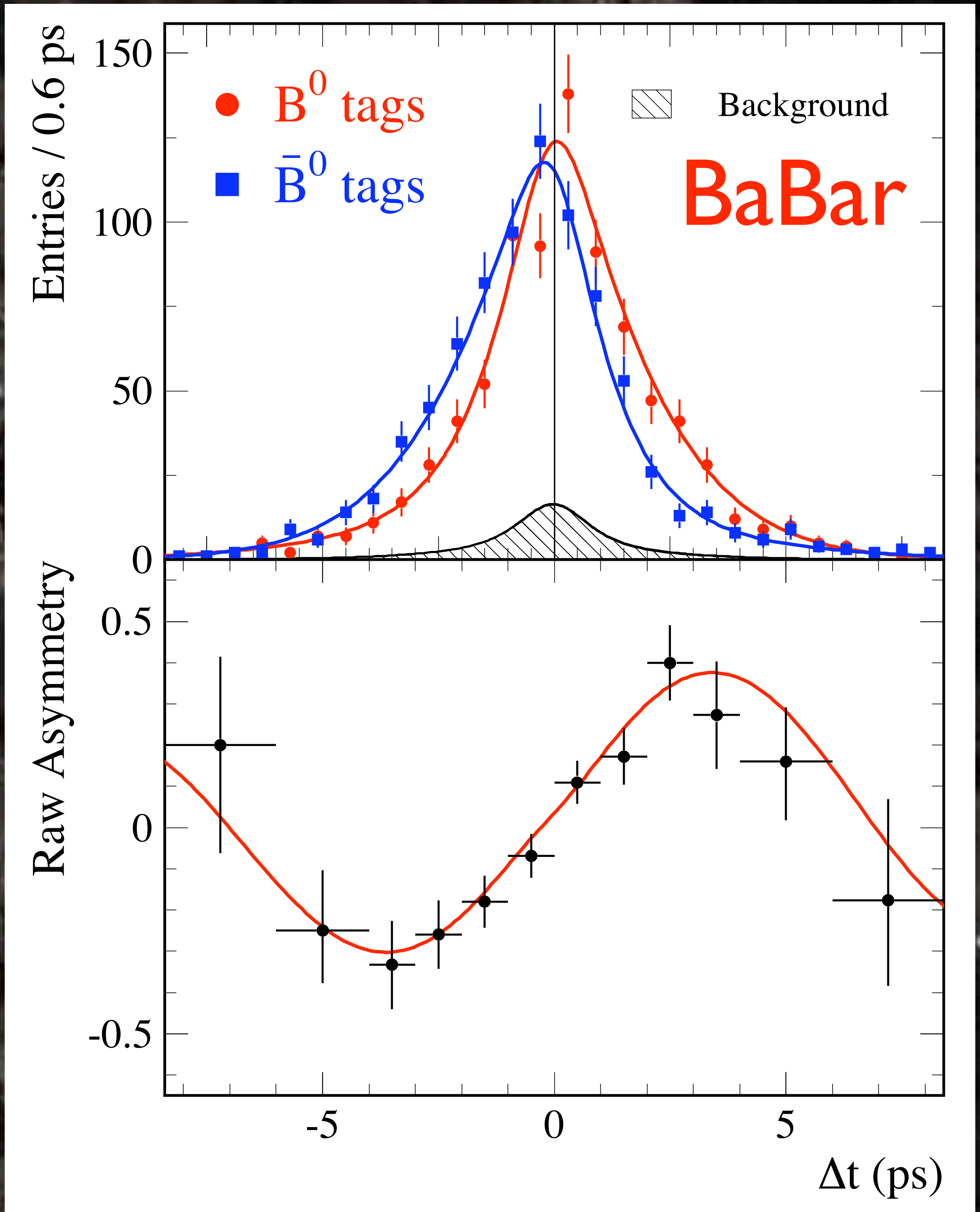

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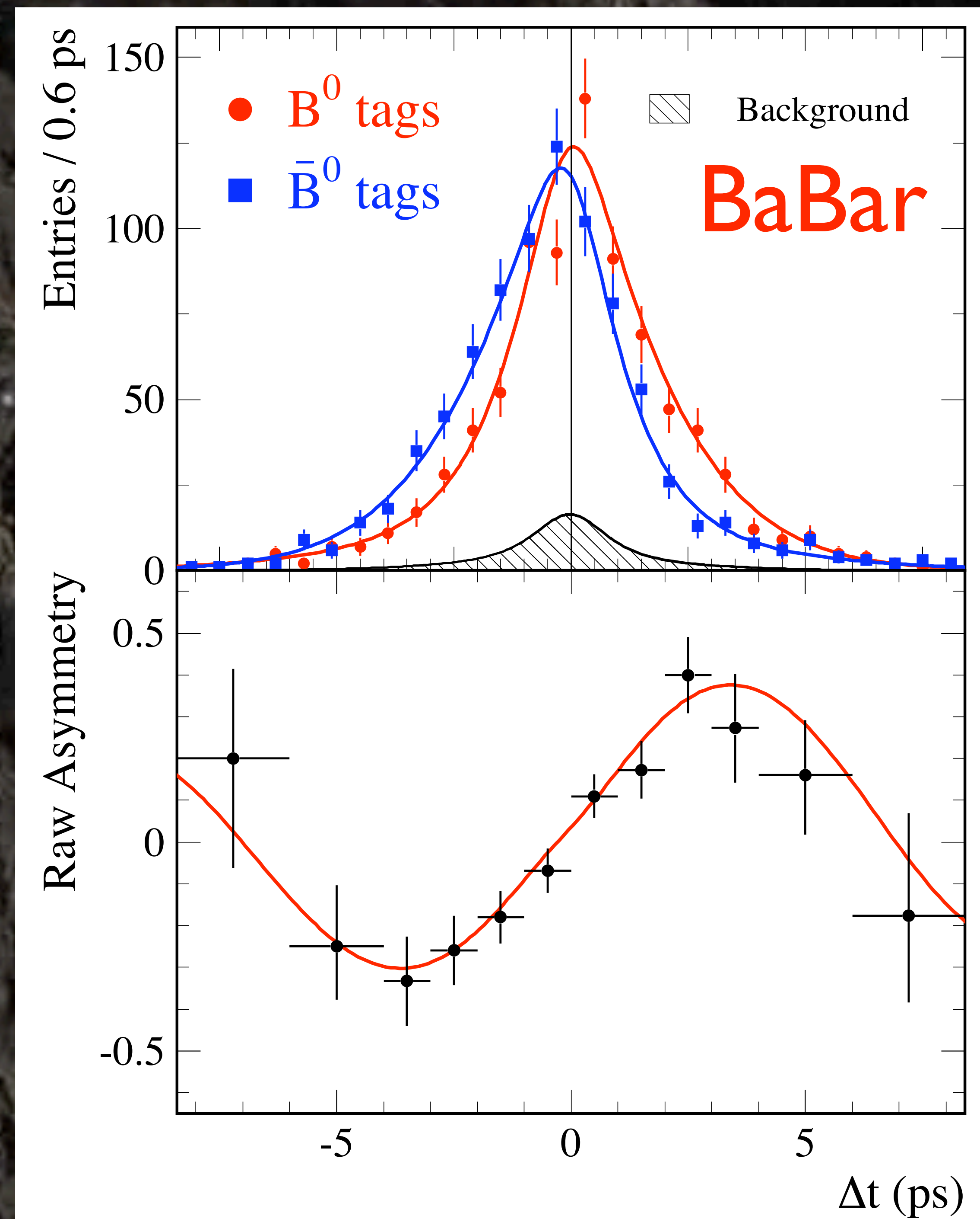
But observed CP violation is not large enough to explain the excess of matter by $\approx 10^{-10}$



Subtle Difference

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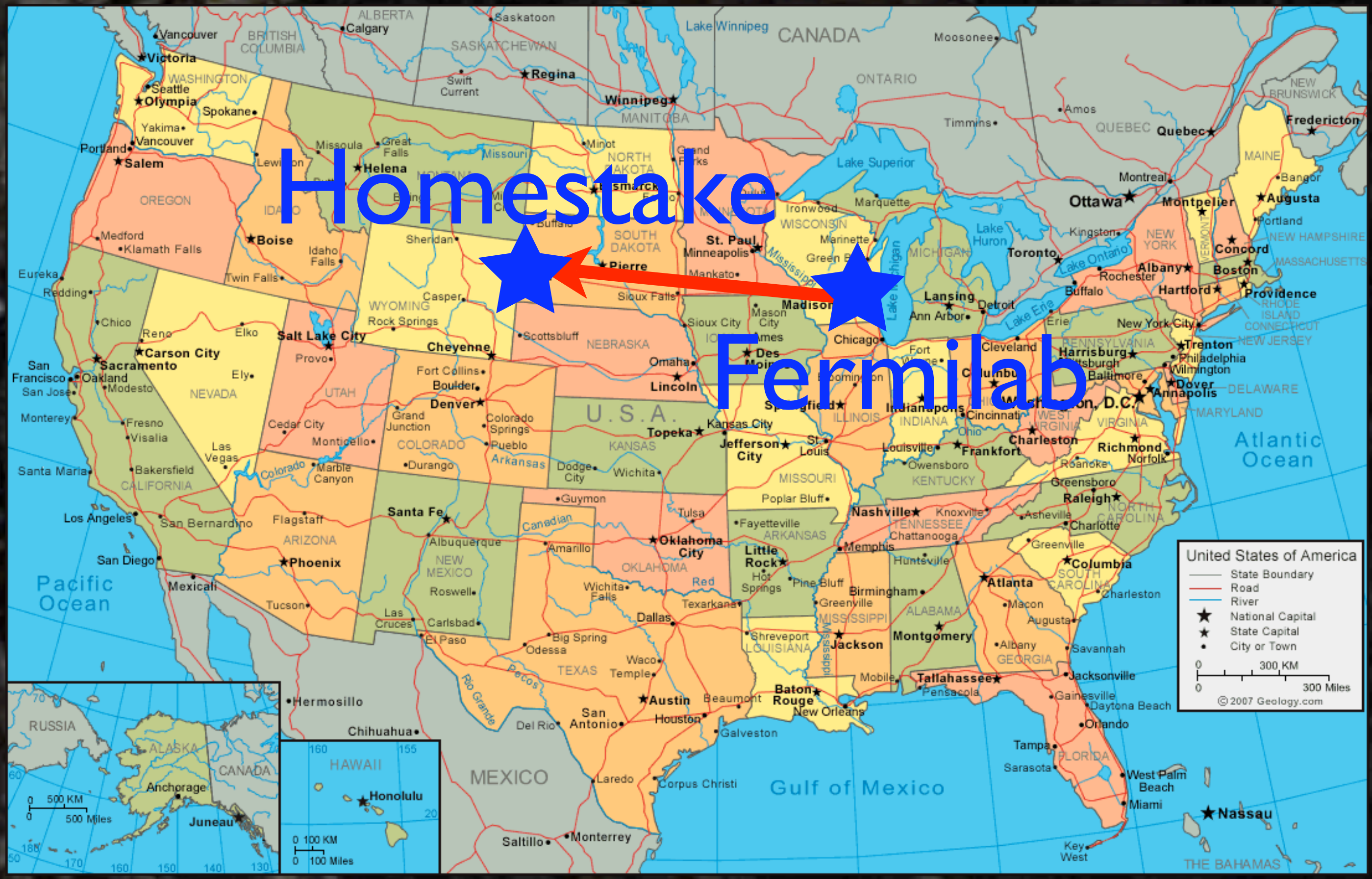
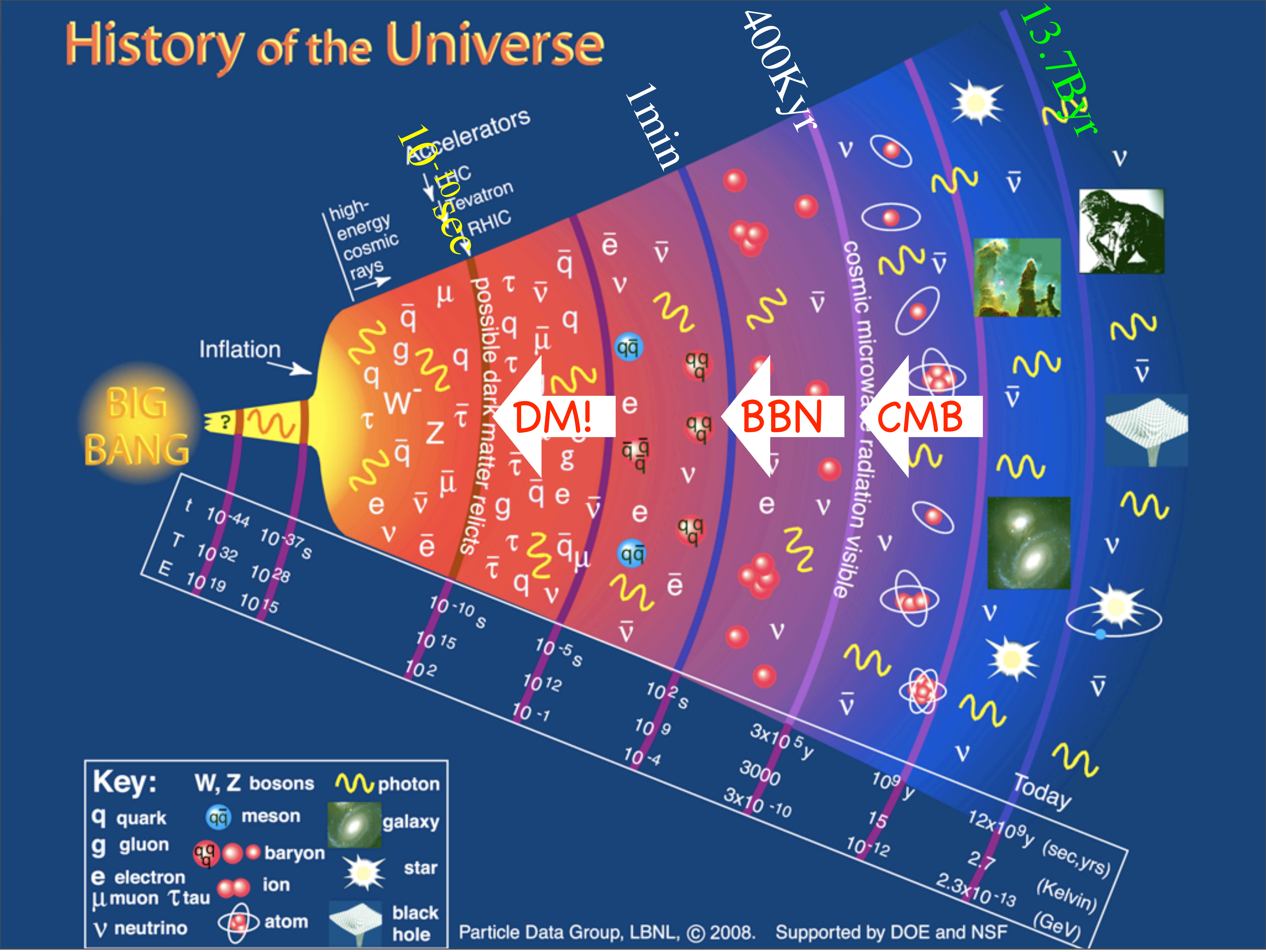
Shoot the neutrino beams over thousands of kilometers to see this subtle difference

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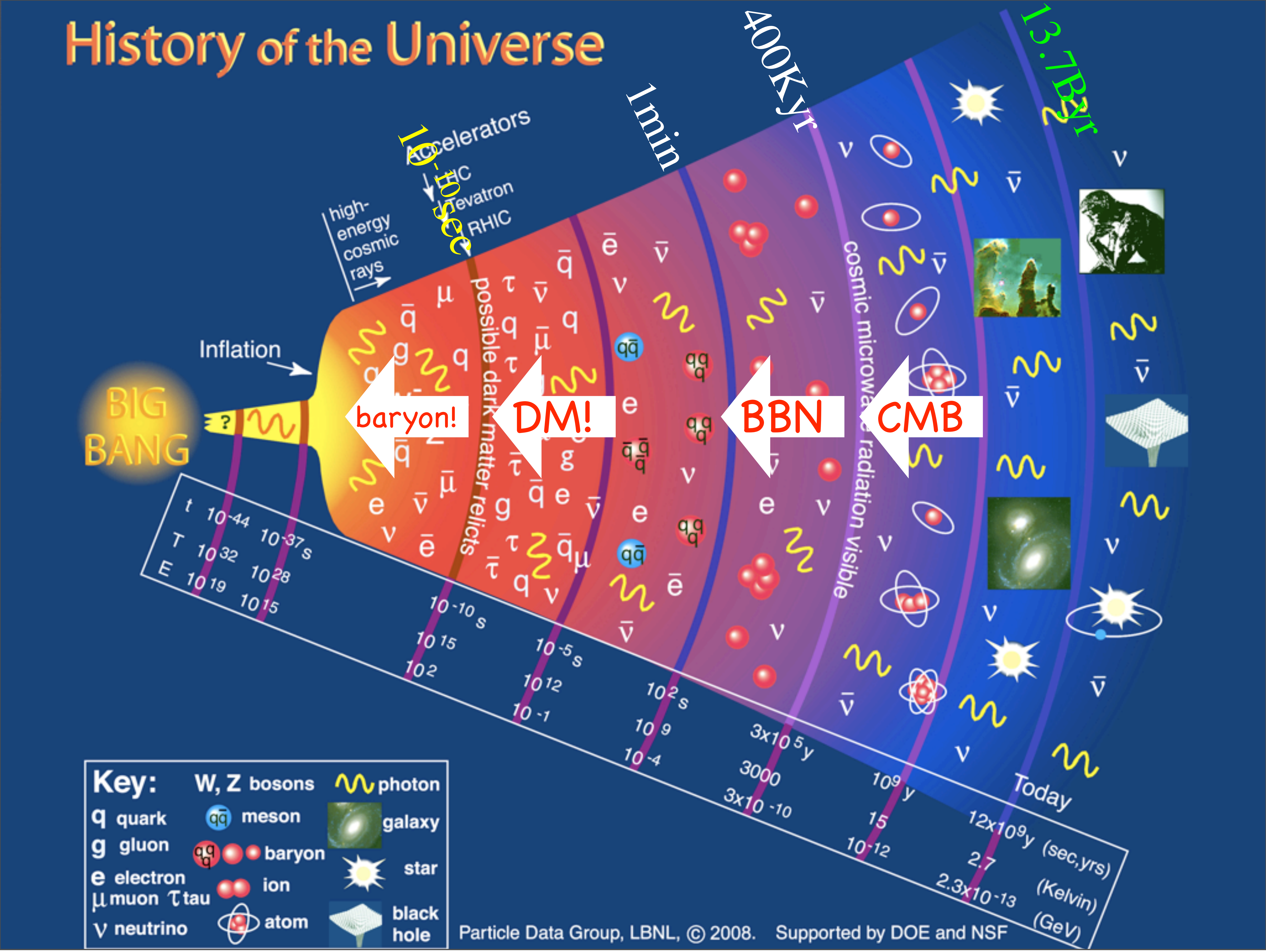
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF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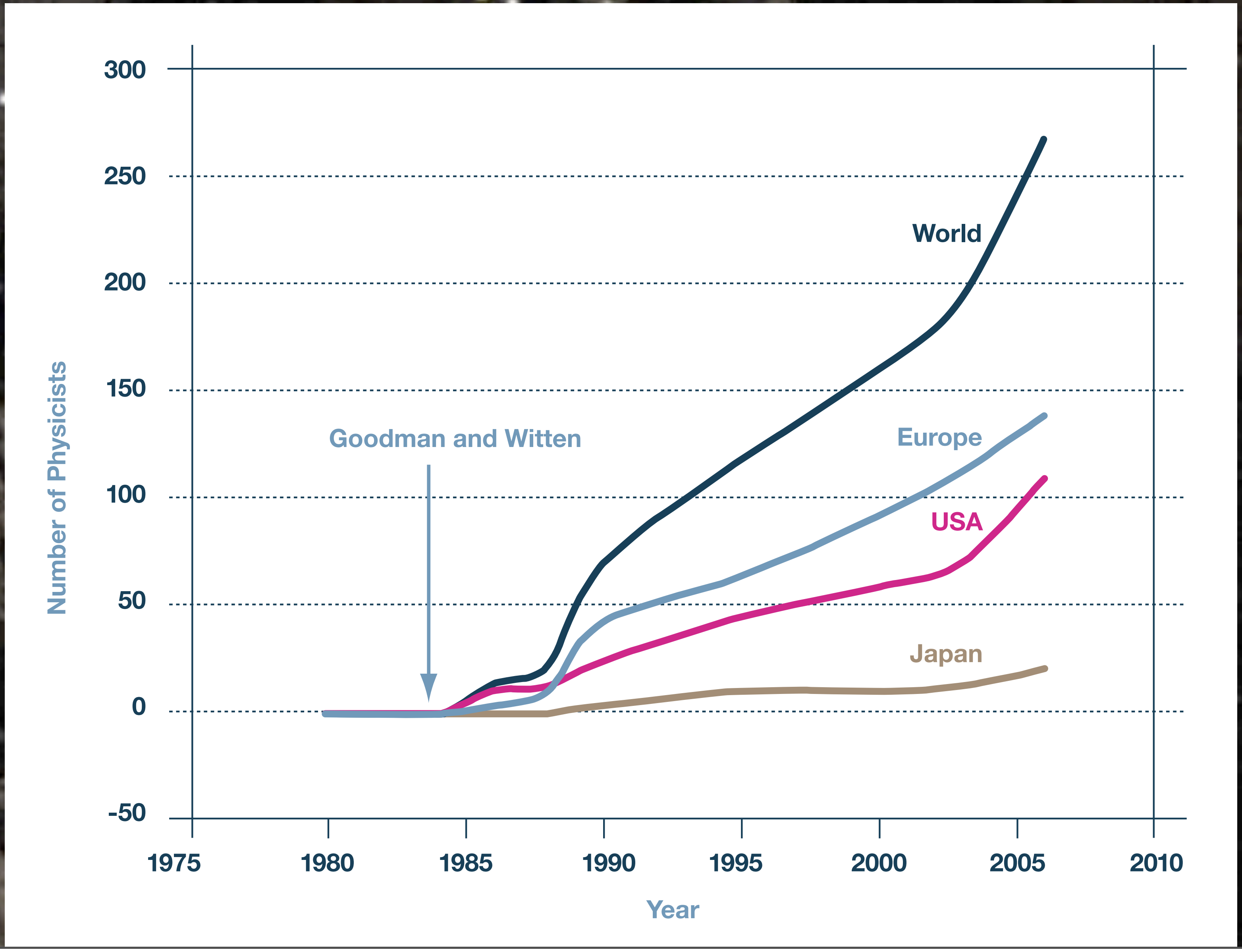
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

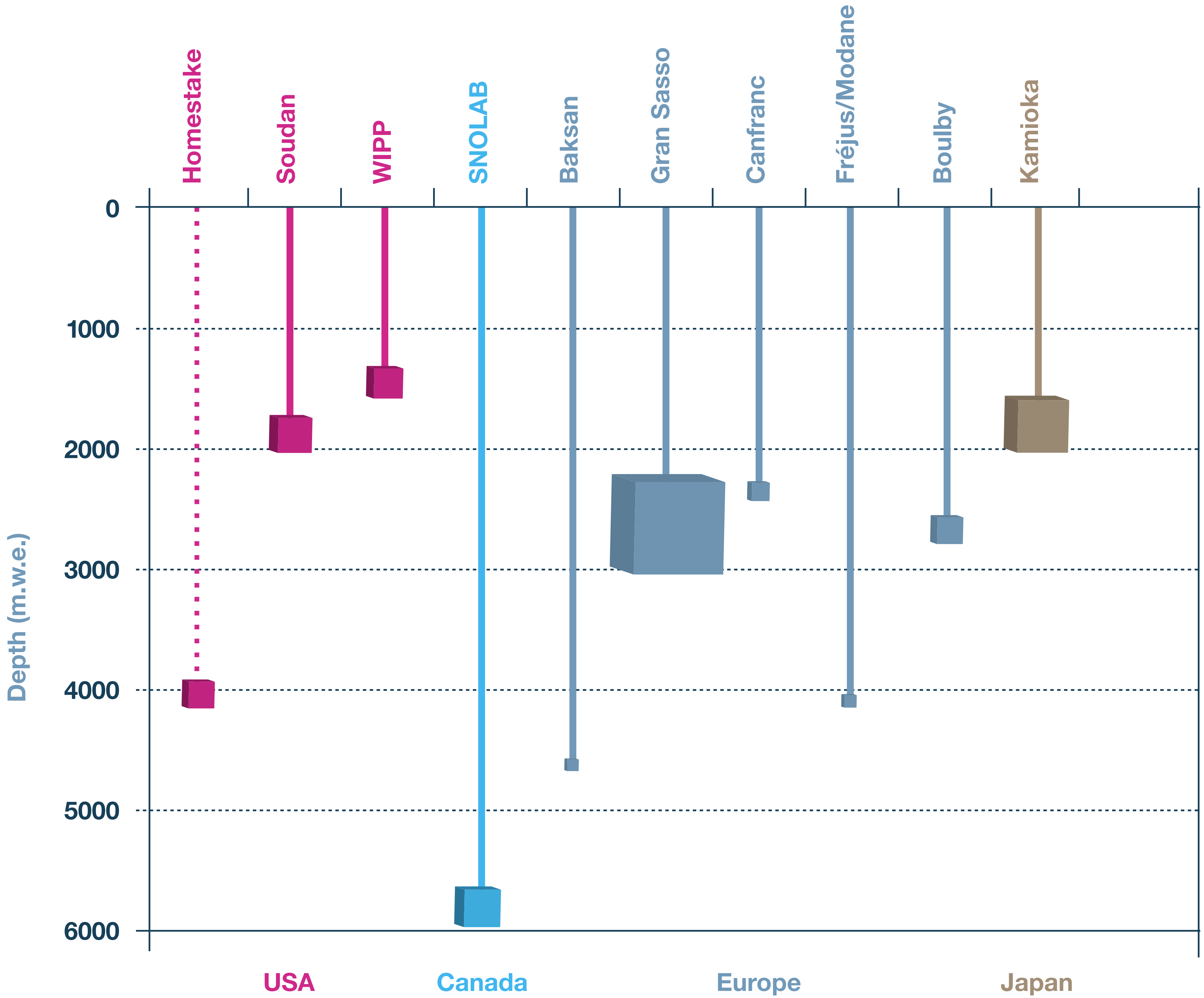
Making It Happen

Growing Community

- number of scientists involved in direct search for dark matter



World Facilities



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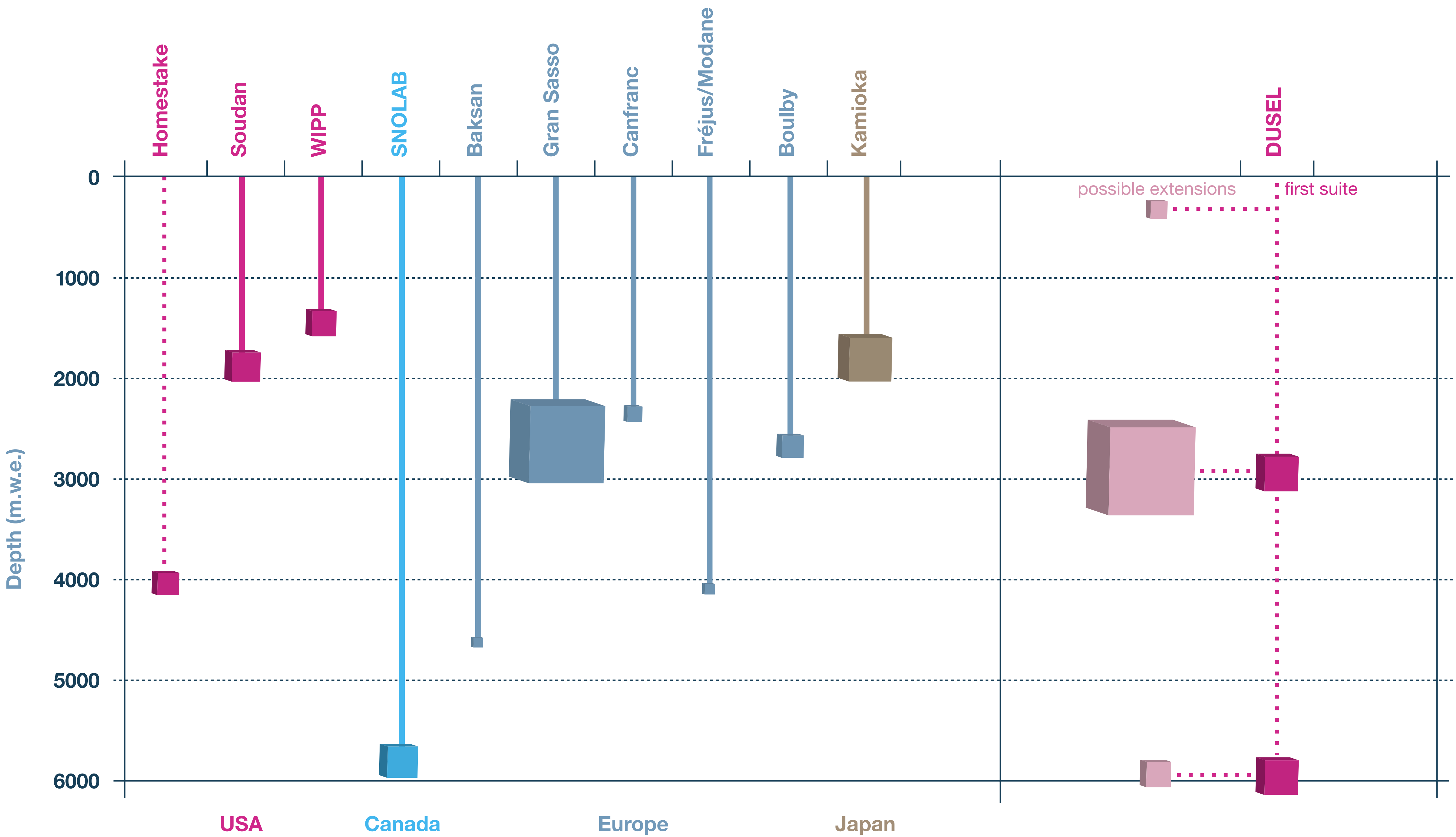

National Science Foundation
WHERE DISCOVERIES BEGIN

National Science Foundation

- *Where should this exciting science to study the universe underground done?*
- Initially many possible sites
- South Dakota state legislature committed $36 million
- down to one in 2007: Homestake

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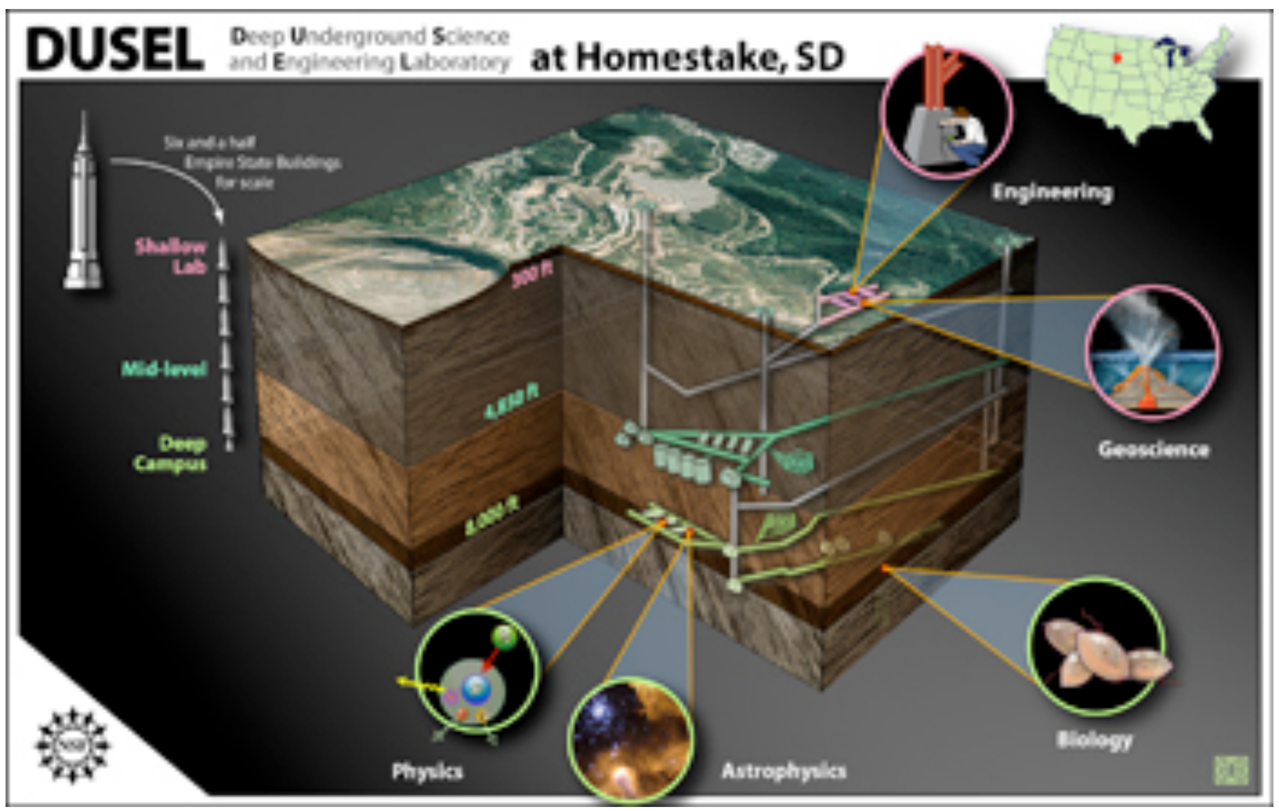
Press Release 07-075

Team Selected for the Proposed Design of the Deep Underground Science and Engineering Laboratory



An artist's rendition of the proposed Deep Underground Science and Engineering Laboratory design.
Credit and Larger Version

July 10, 2007

The National Science Foundation (NSF) today announced selection of a University of California-Berkeley proposal to produce a technical design for a Deep Underground Science and Engineering Laboratory (DUSEL) at the former Homestake gold mine near Lead, S.D. The Homestake team, headed by Kevin Lesko, could receive up to $5 million per year for up to three years.

A 22-member panel of external experts, all screened for conflicts of interest, exhaustively merit-reviewed proposals from four teams and unanimously determined that the Homestake proposal offered the greatest potential for developing a DUSEL, and NSF concurred with the panel's recommendation. The agency's selection of the Homestake proposal provides funding only for design work. Any decision to construct and operate a DUSEL would entail a sequence of approvals by NSF and the National Science Board; funding would then have to be requested by the Administration and approved by Congress.

"We are excited about the opportunities in underground research and education that a DUSEL would provide and look forward to working with all of the research communities to develop a well-conceived plan for this unique, world-leading facility at the Homestake Mine," said Tony Chan, assistant director for the NSF Directorate of Mathematical and Physical Sciences. "In tandem with the design of the facility infrastructure, NSF also will begin working with researchers to identify the initial suite of experiments that might be deployed in DUSEL."

Over the past decade, a dozen "blue-ribbon" independent reports from the National Academies and multiagency government committees have emphasized the need for a DUSEL, and various candidate sites have been discussed. In September 2006, NSF solicited proposals to produce technical designs for a DUSEL at one specific site. By the January 2007 deadline, four teams, each focusing on a different location, had submitted proposals.

The review panel included outside experts from relevant science and engineering communities and from supporting fields such as human and environmental safety, underground construction and operations, large project management, and education and outreach. Scientists from Japan, Italy, the United Kingdom and Canada also served on the panel. The review process included site visits by panelists to all four locations, and two meetings to review the information, debate and vote on which--if any--of the proposals would be recommended for funding.

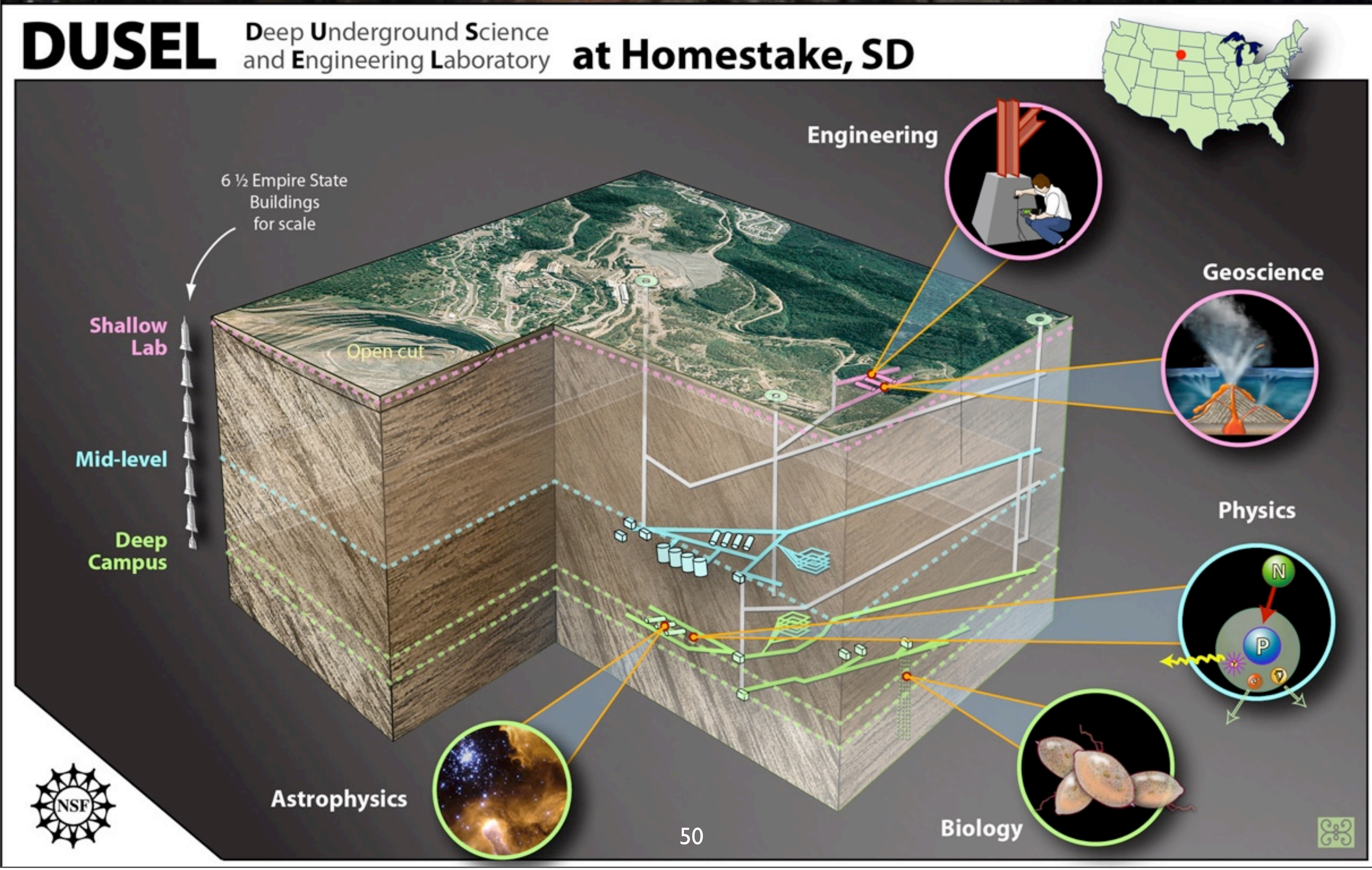
The concept of DUSEL grew out of the need for an interdisciplinary "deep science" laboratory that would allow researchers to probe some of the most compelling questions in modern science. Among them: What are the invisible dark matter and dark energy that comprise more than 95 percent of everything visible in the universe? What is the nature of ghostly particles called neutrinos that pervade the cosmos, but almost never interact with matter, and what can certain kinds of extremely rare radioactivity and particle decay reveal about the fundamental behavior of atoms? Will this site help reliably predict and control earthquakes? What are the characteristics of microorganisms at great depth?

Those and other crucial questions can only be investigated at great depth, where thousands of feet of rock can shield ultra-sensitive physics experiments from background activity, and where geoscientists, biologists and engineers can have direct access to geological structures, tectonic processes and life forms that cannot be studied fully in any other way. Several countries, including Canada, Italy and Japan, have extensive deep science programs. The United States has no existing facilities below a depth of 1 kilometer.

If eventually built as envisioned by its supporters, a Homestake DUSEL would be the largest and deepest facility of its kind in the world.

-NSF-

A Lot of Science



Kick-start

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Sanford Laboratory at Homestake

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Raising the next generation

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  NRC Report "Rising above the Gathering Storm" & ACI

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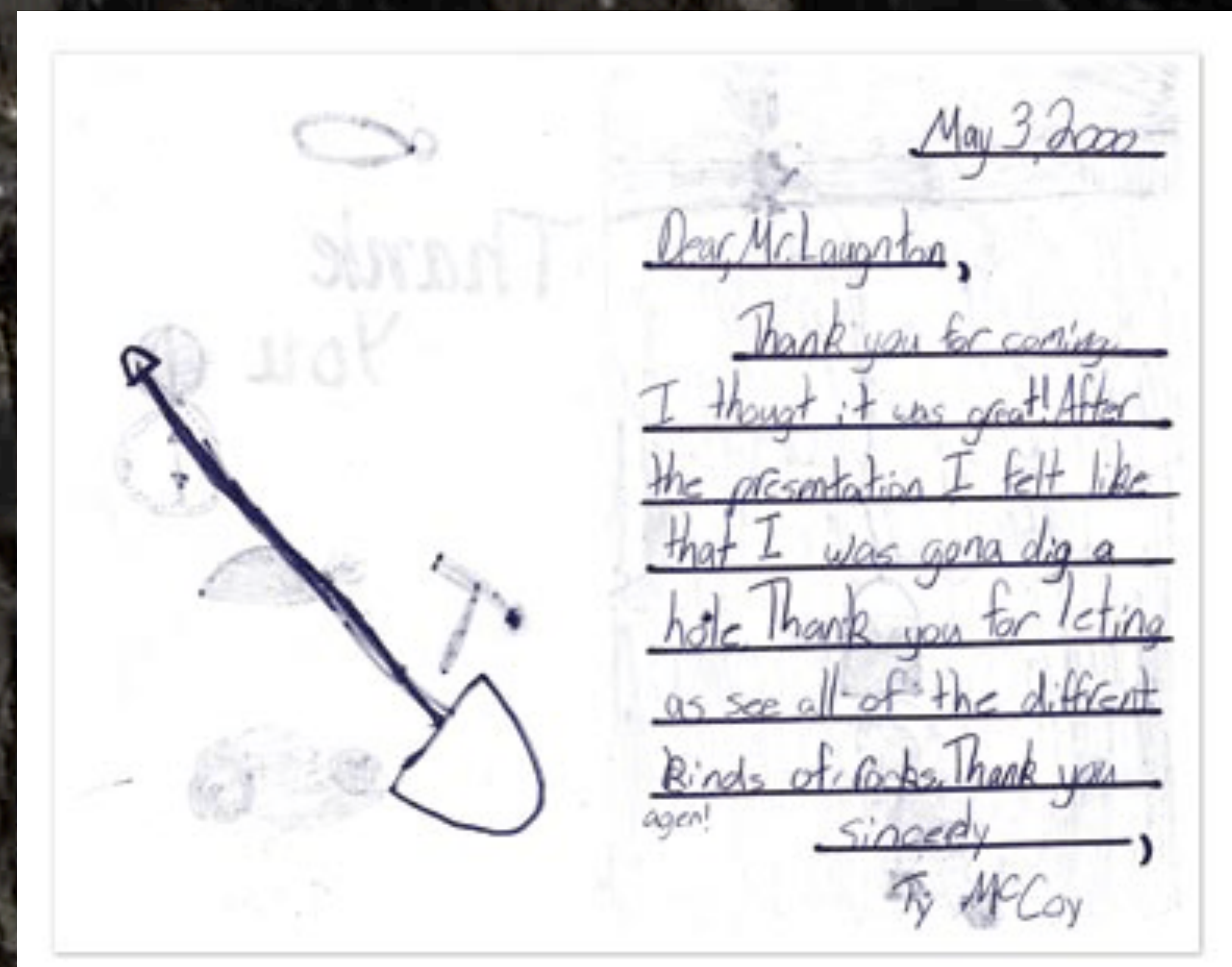

Attracting Kids to Science

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Cosmic Questions for DUSEL

What is the Universe made of?

What is Dark Matter?

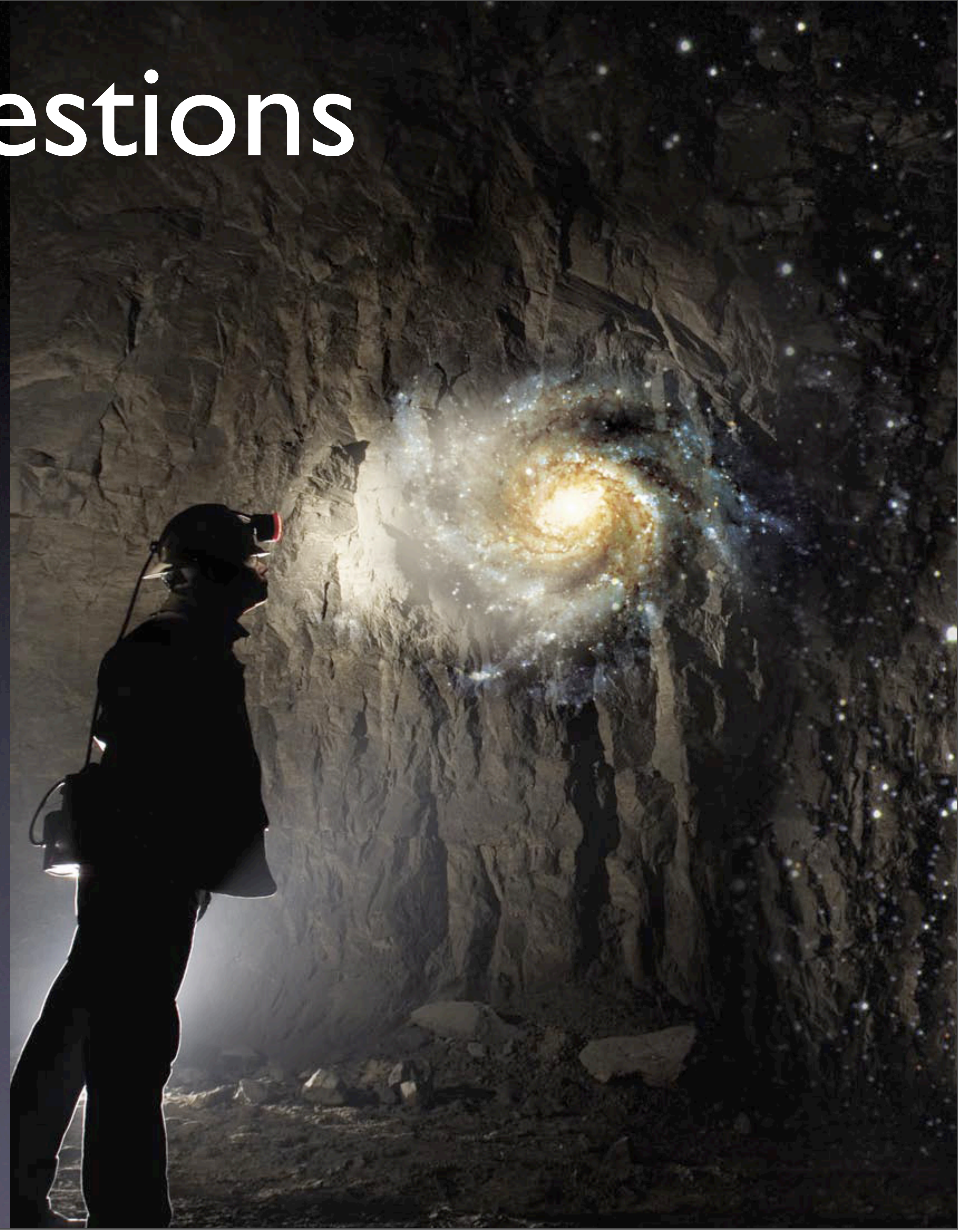
Did neutrinos form galaxies?

Where did the Anti-Matter go?

Where did we come from?

We need to go underground to answer the cosmic questions!

Captivate the young minds, nurture the next generation



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